Results from the Göttingen Turbulence Facility

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High **P**ressure **C**onvection **F**acility

Variable **D**ensity **T**urbulence **T**unnel

Prandtl's **F**riction **T**unnel

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Max Planck Institute for Dynamics and Self-Organization

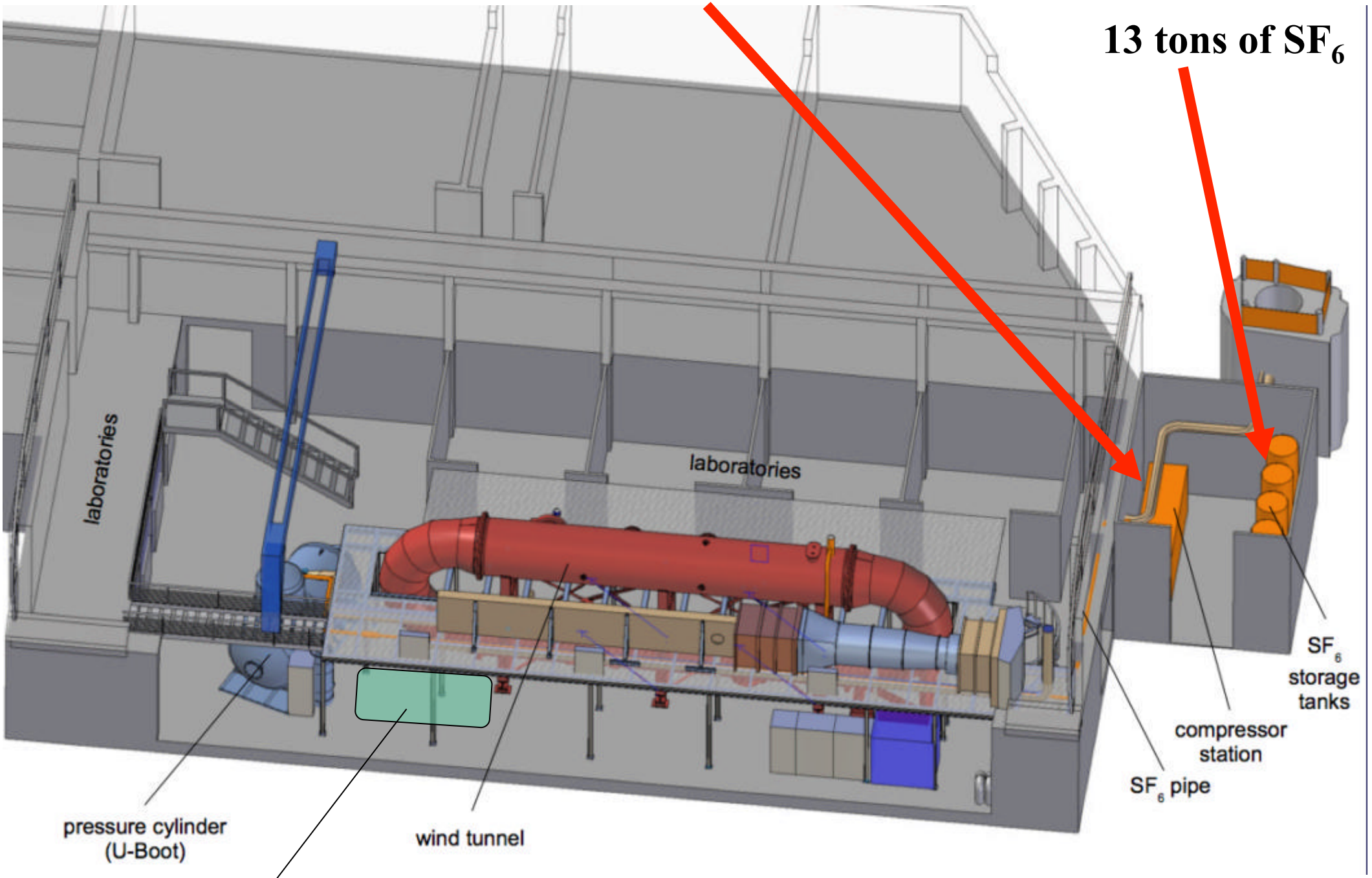
Objectives of the Facility

- variable density
- tunable kinematic viscosity
- high Reynolds numbers
- high Rayleigh numbers
- dissipation scales resolvable by Lagrangian Particle Tracking
- mean flows sufficiently slow for observations
- affordable

➔ use of room temperature gases at pressures 1mBar to 20 Bar (Air, Nitrogen, Helium, SF_6)

➔ pressure vessels and gas handling system

liquefier

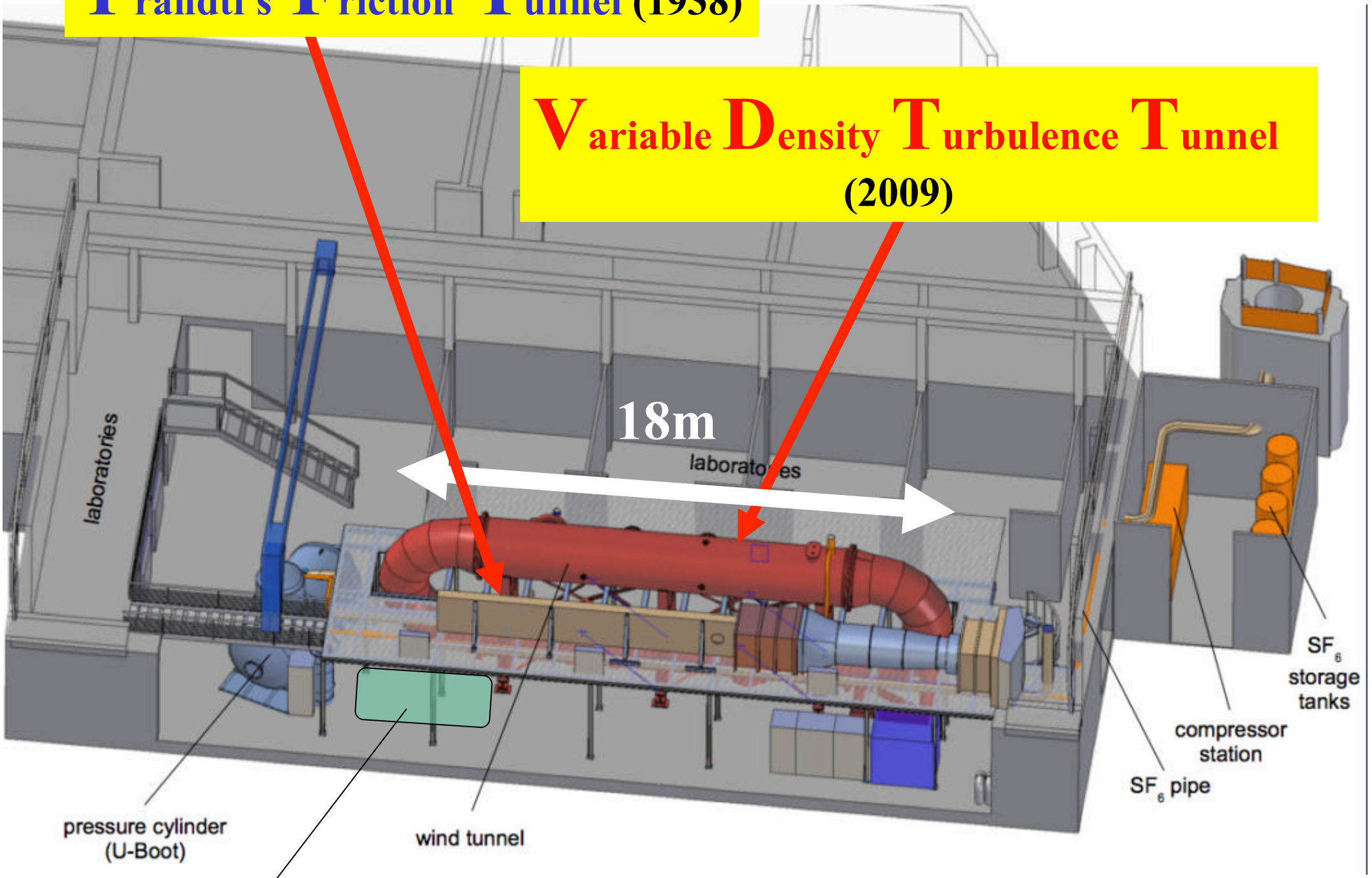

13 tons of SF_6
laboratories
laboratories
SF_6 storage tanks
compressor station
SF_6 pipe
pressure cylinder (U-Boot)
wind tunnel
Pressure cylinder (cigar)

Gas handling facility:

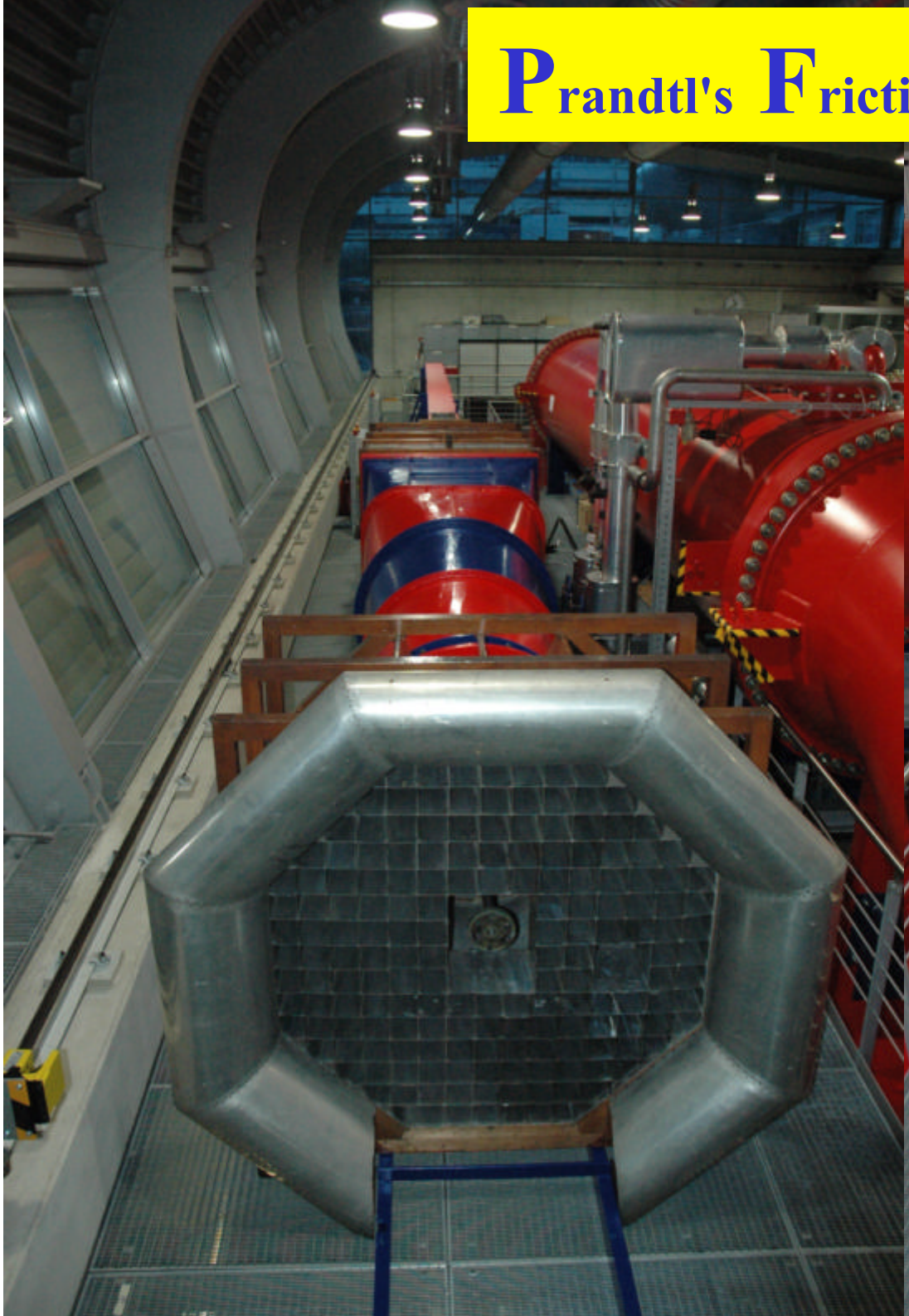
- storage of 13 tons of SF_6
- fill station and liquefier
- pressure 1mbar to 19 bar
- other gases

Prandtl's Friction Tunnel (1938)

Variable Density Turbulence Tunnel (2009)

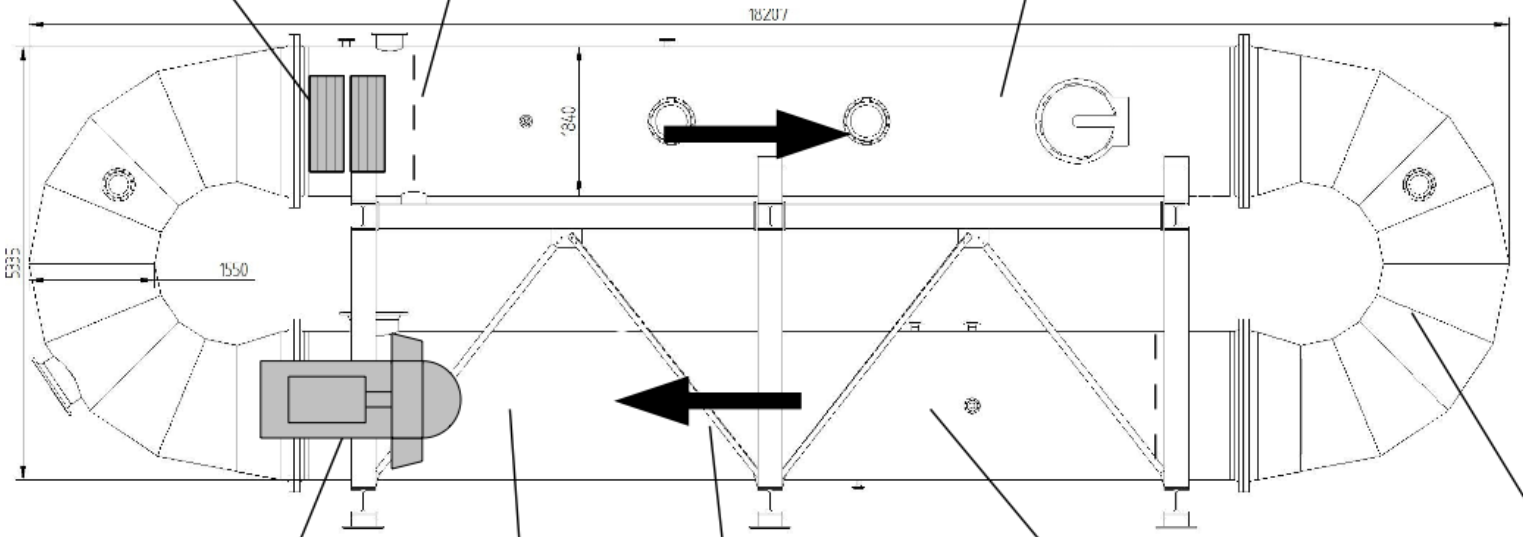


Prandtl's Friction Tunnel (1938)



Variable Density Turbulence Tunnel

(2009)



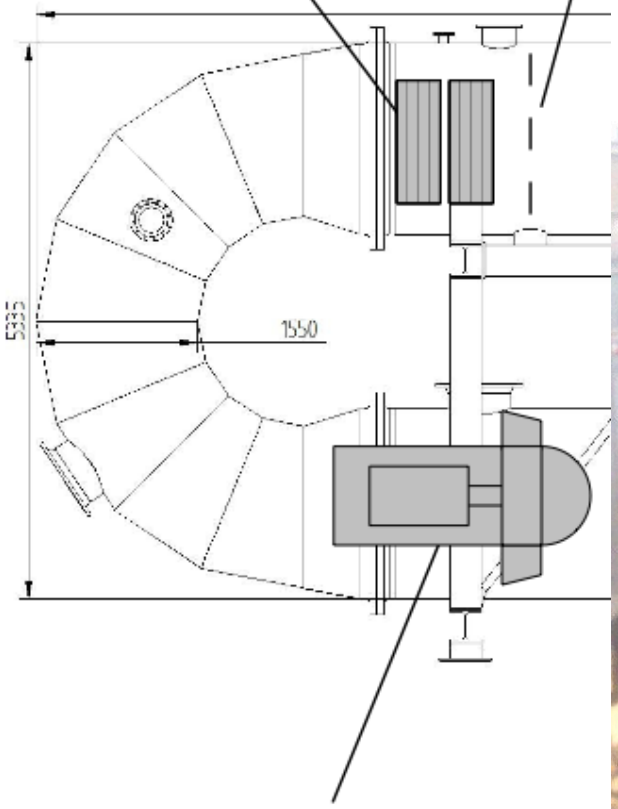
Two heat exchanges,
cooling power: 240kW

Active or pa
at the entra
measureme

Total weight:
ca. 35t

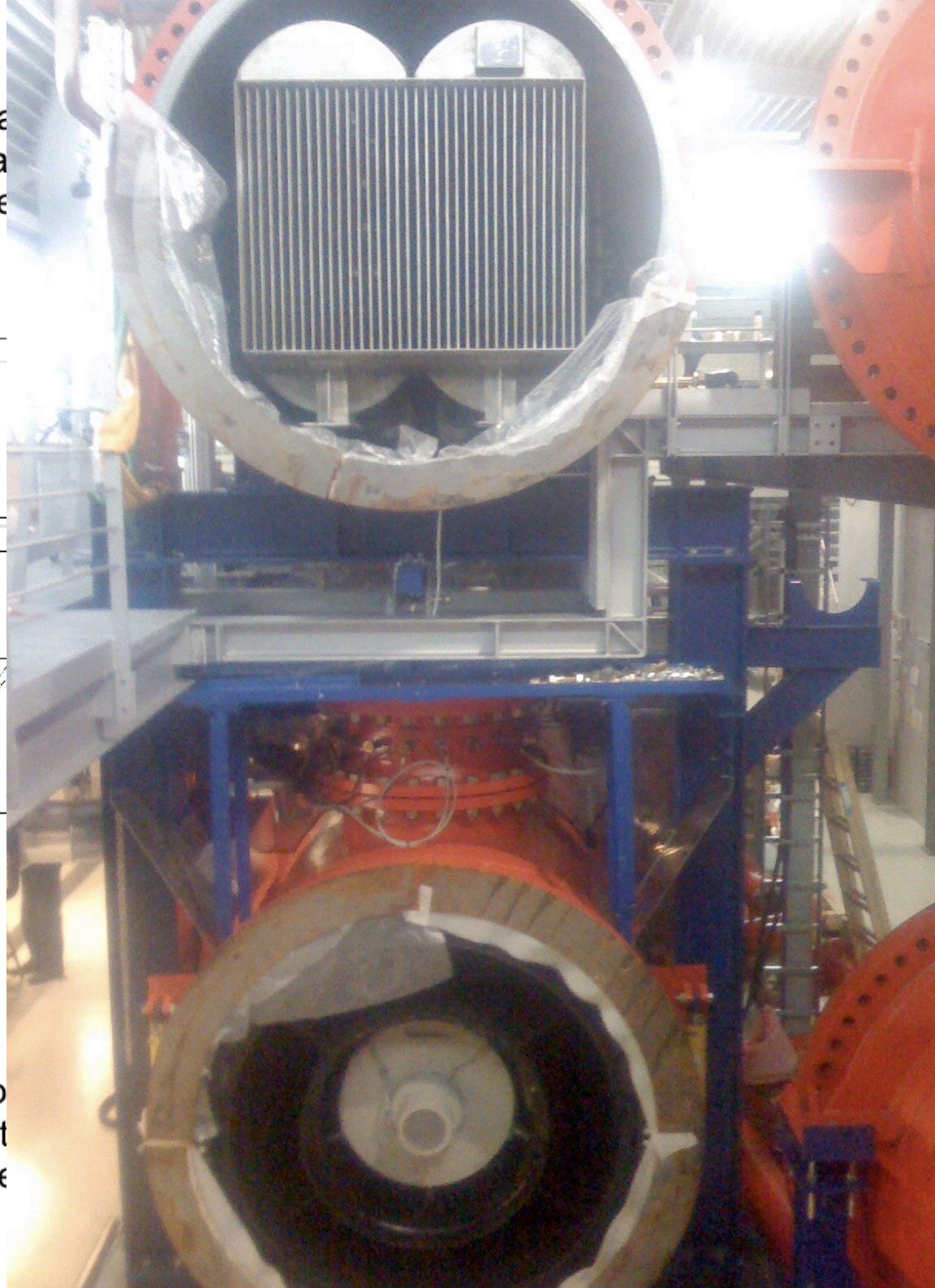
Total volume:
85m^3

Total height:
6 m

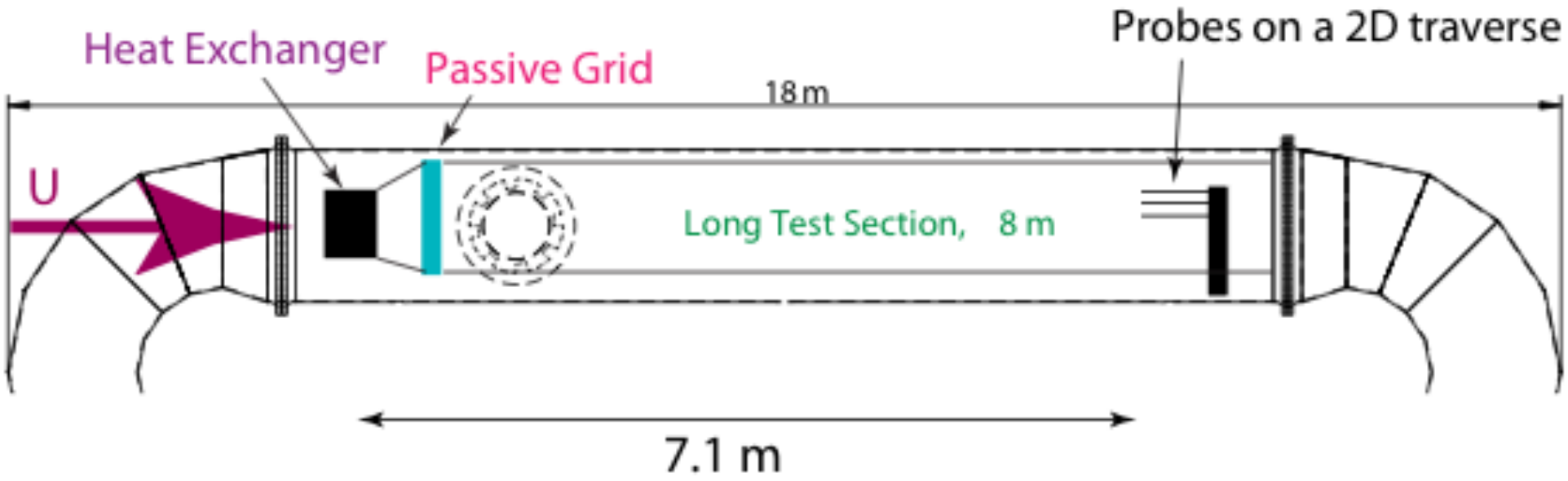


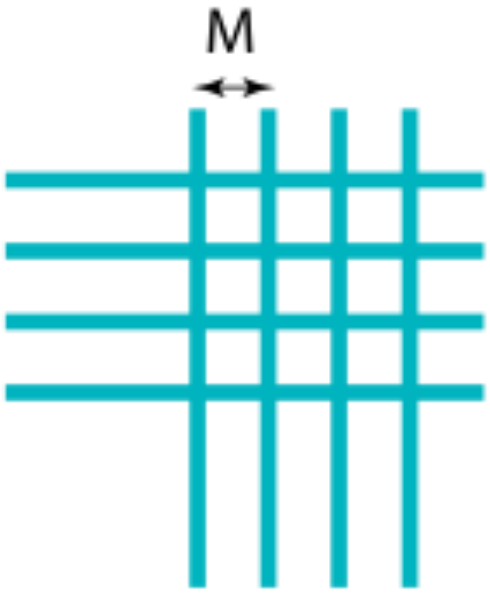
Fan, mechanical
power: 210kW,
additional cooling
power: 40kW

Quick lo
access t
measure



Passive grid turbulence



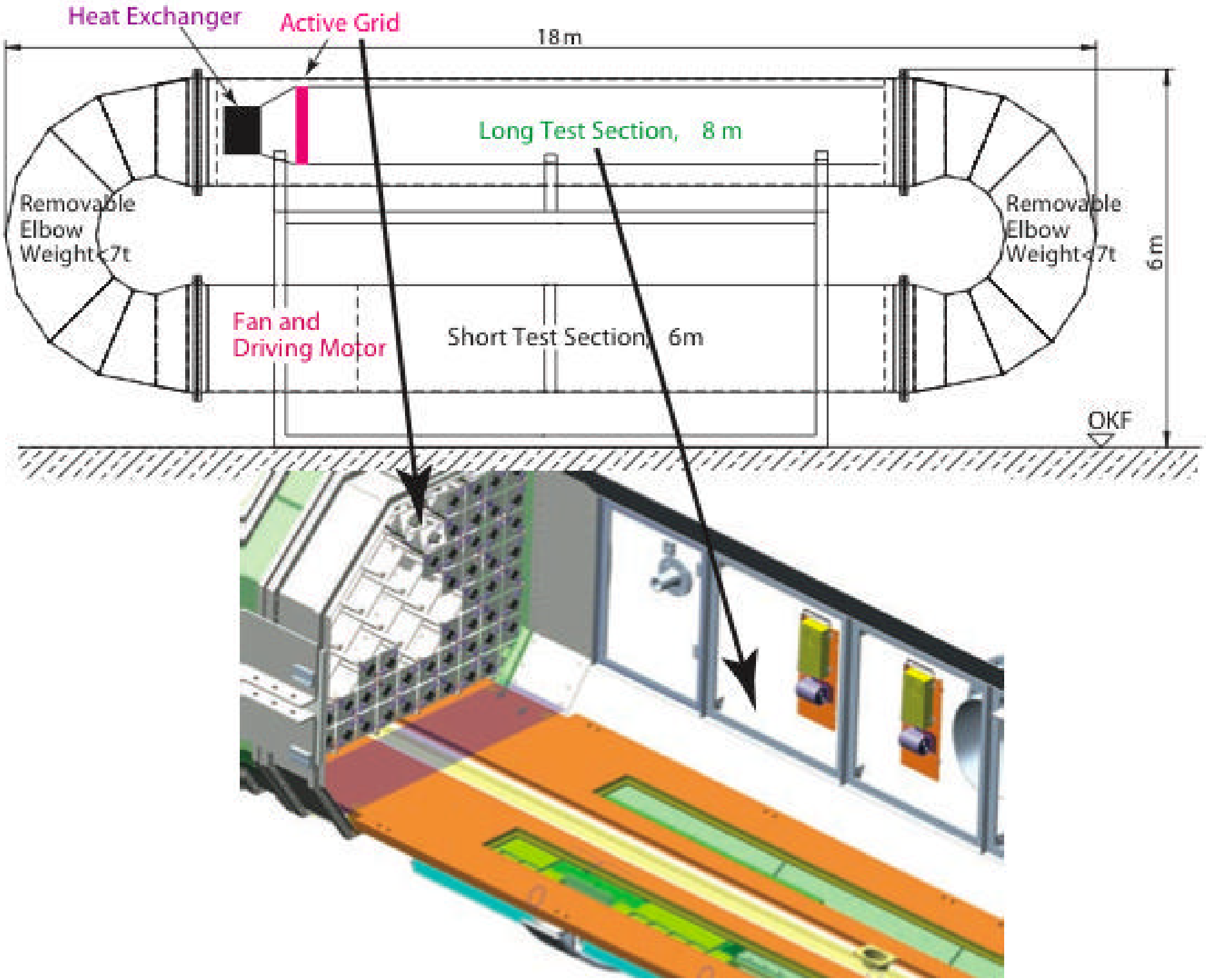


Passive Grid:

biplanar mesh of square bars with 35% solidity

mesh spacing, M = 107 mm

probes are x/M = 67 meshes downstream

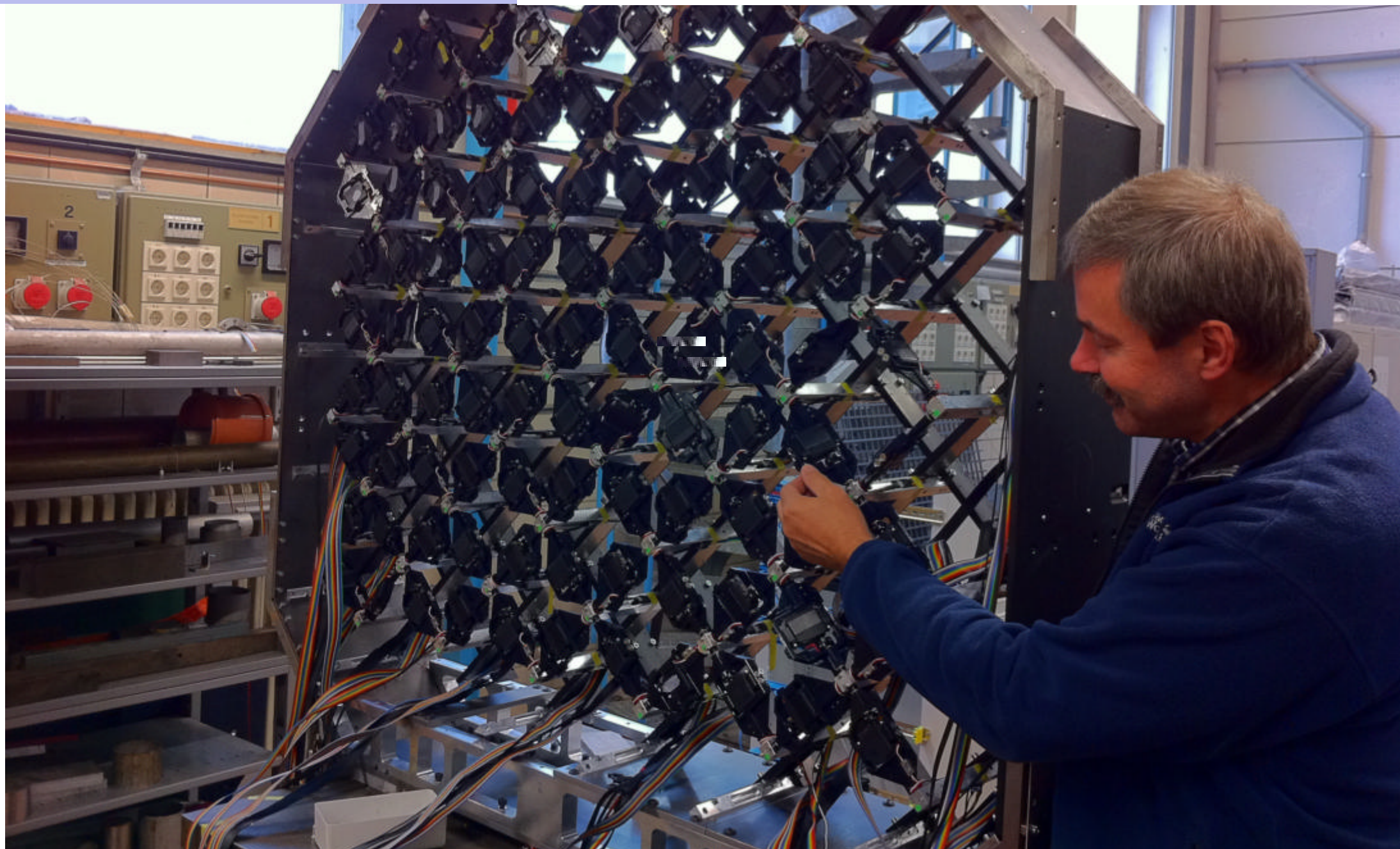

Heat Exchanger
Active Grid
18 m
Long Test Section, 8 m
Removable
Elbow
Weight <7t
Removable
Elbow
Weight <7t
6 m
Fan and
Driving Motor
Short Test Section, 6m
OKF

Active Grid

M = 163 mm

130 independent position controlled winglets

rotate through 180 degrees at up to 2 Hz



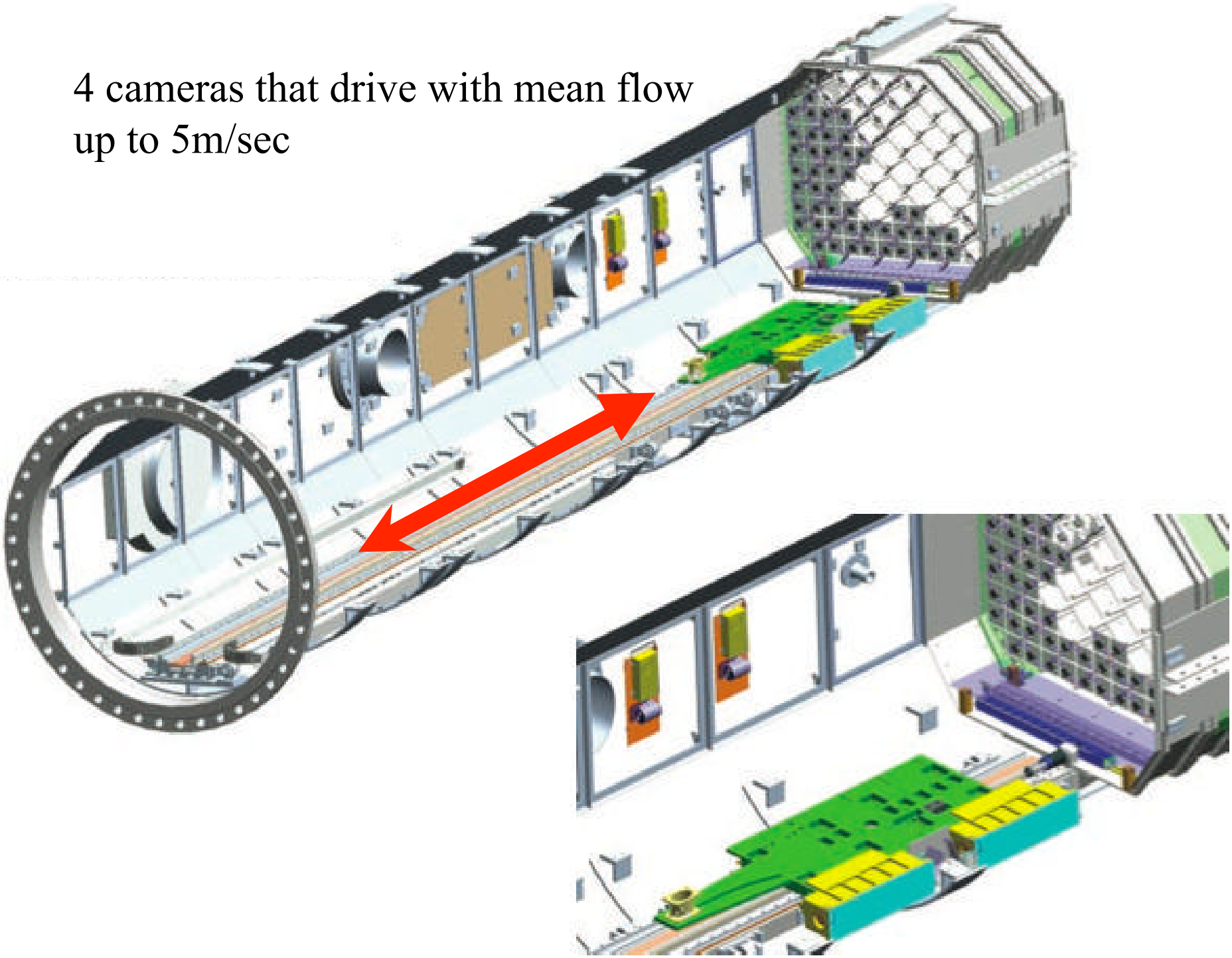
Active Grid

M = 163 mm

130 independent position controlled winglets

rotate through 180 degrees at up to 2 Hz

4 cameras that drive with mean flow
up to 5m/sec



ultra-high Reynolds number at measurable scales

Working fluid	Pressure (bar)	ρ (kg/m^3)	ν (10^{-6}m^2/s)	Motor Power (kW)	U (m/s)	u' (m/s)	ϵ (m^2/s^3)	Re	R_λ	η (μm)	τ_η (ms)
SF_6	15	106.6	0.16	168	5.0	1.0	1.33	4.2×10^6	8000	7.5	0.35
SF_6	15	106.6	0.16	1.3	1.0	0.2	0.01	8.2×10^5	3500	25	4.0
SF_6	10	65.6	0.24	104	5.0	1.0	1.33	2.8×10^6	6500	10	0.43
SF_6	1	5.86	2.64	9.2	5.0	1.0	1.33	2.6×10^5	2000	61	1.4
Air	15	19.4	0.93	31	5.0	1.0	1.33	7.3×10^5	3300	38	1.0
Air	15	19.4	0.93	0.23	1.0	0.2	0.01	1.4×10^5	1500	95	9.6
Air	10	12.9	1.4	20	5.0	1.0	1.33	4.8×10^5	2700	38	1.0
Air	1	1.29	14.0	2.0	5.0	1.0	1.33	4.8×10^4	850	210	3.2

Table 1: Estimated parameters in the Göttingen turbulence tunnel using active grids. The integral length scale is assumed to be $L = 0.45D = 0.68$m. The turbulence intensity is assumed to be $u'/U = 25\%$.

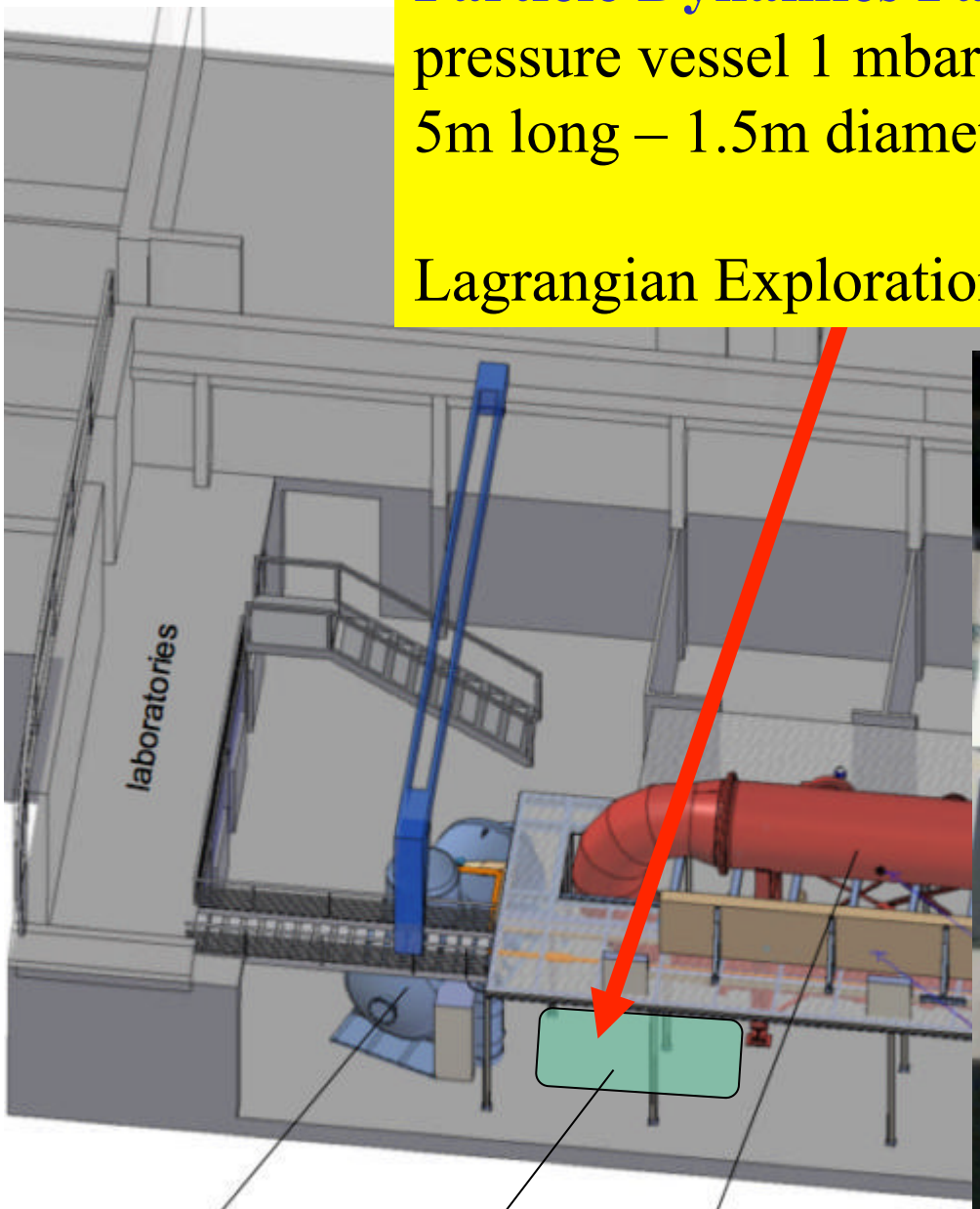
Change by 1. kinematic viscosity
2. driving

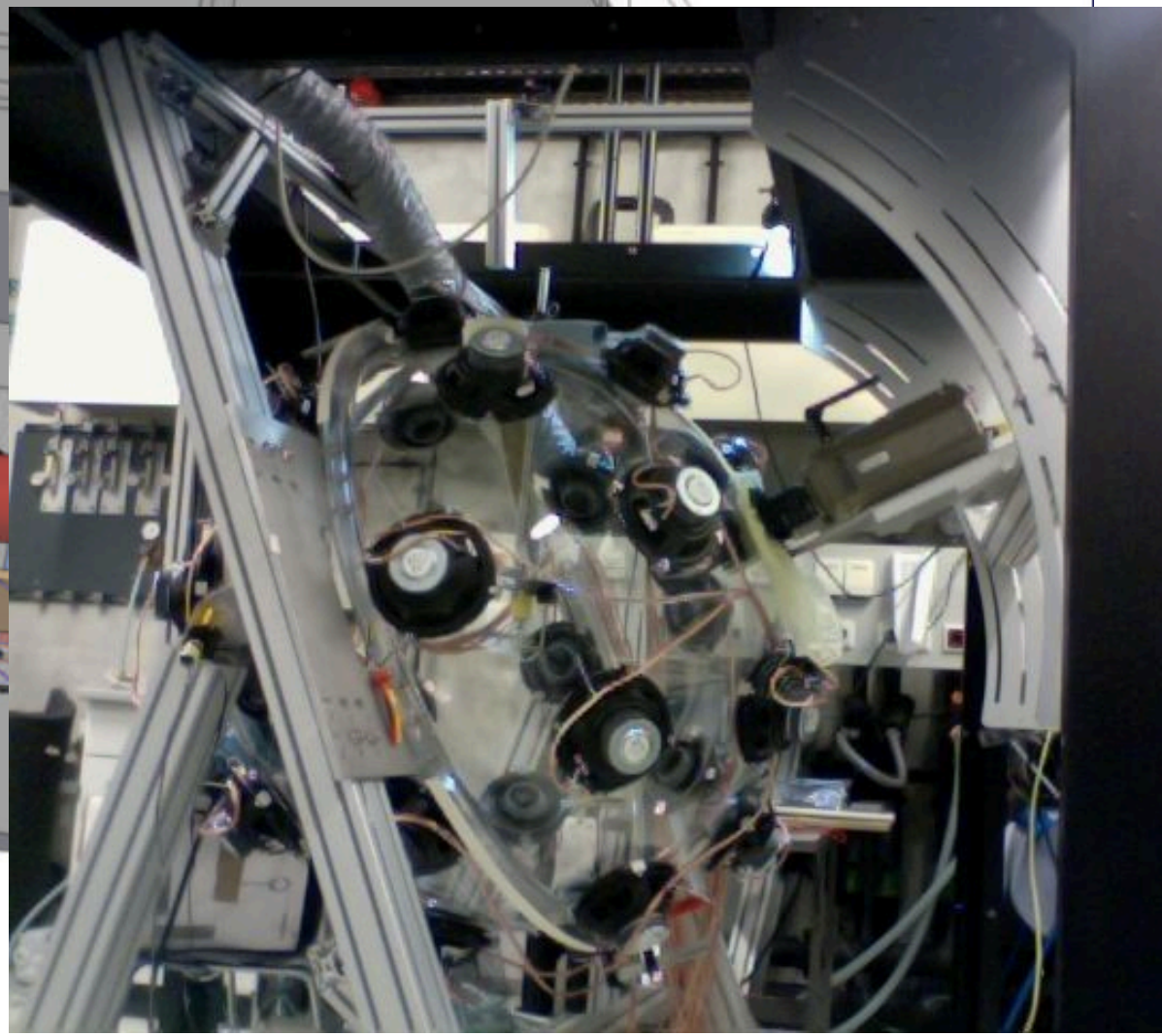
particle tracking will be possible.

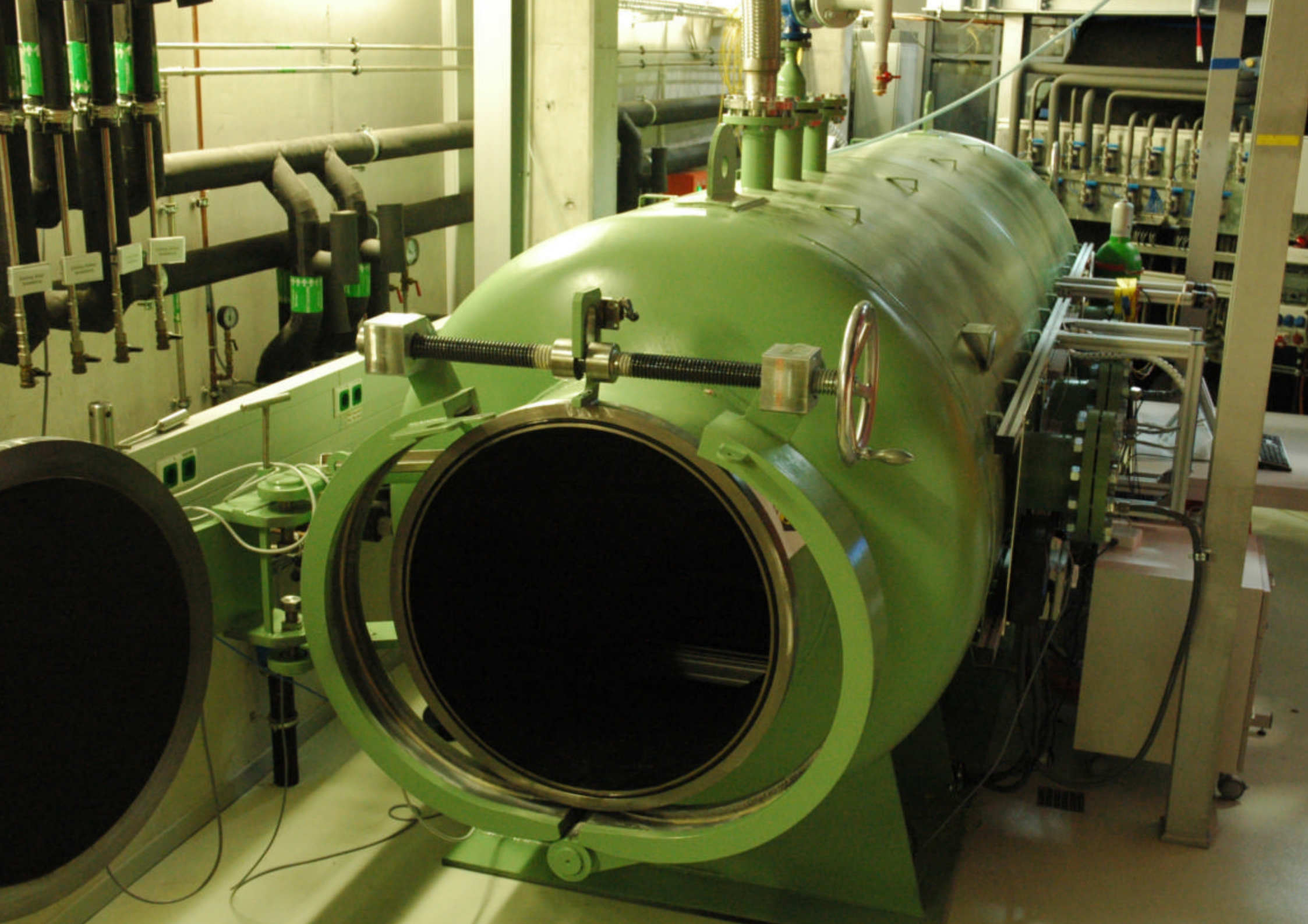
Particle Dynamics Facility (Cigar)

pressure vessel 1 mbar – 20 bar
5m long – 1.5m diameter

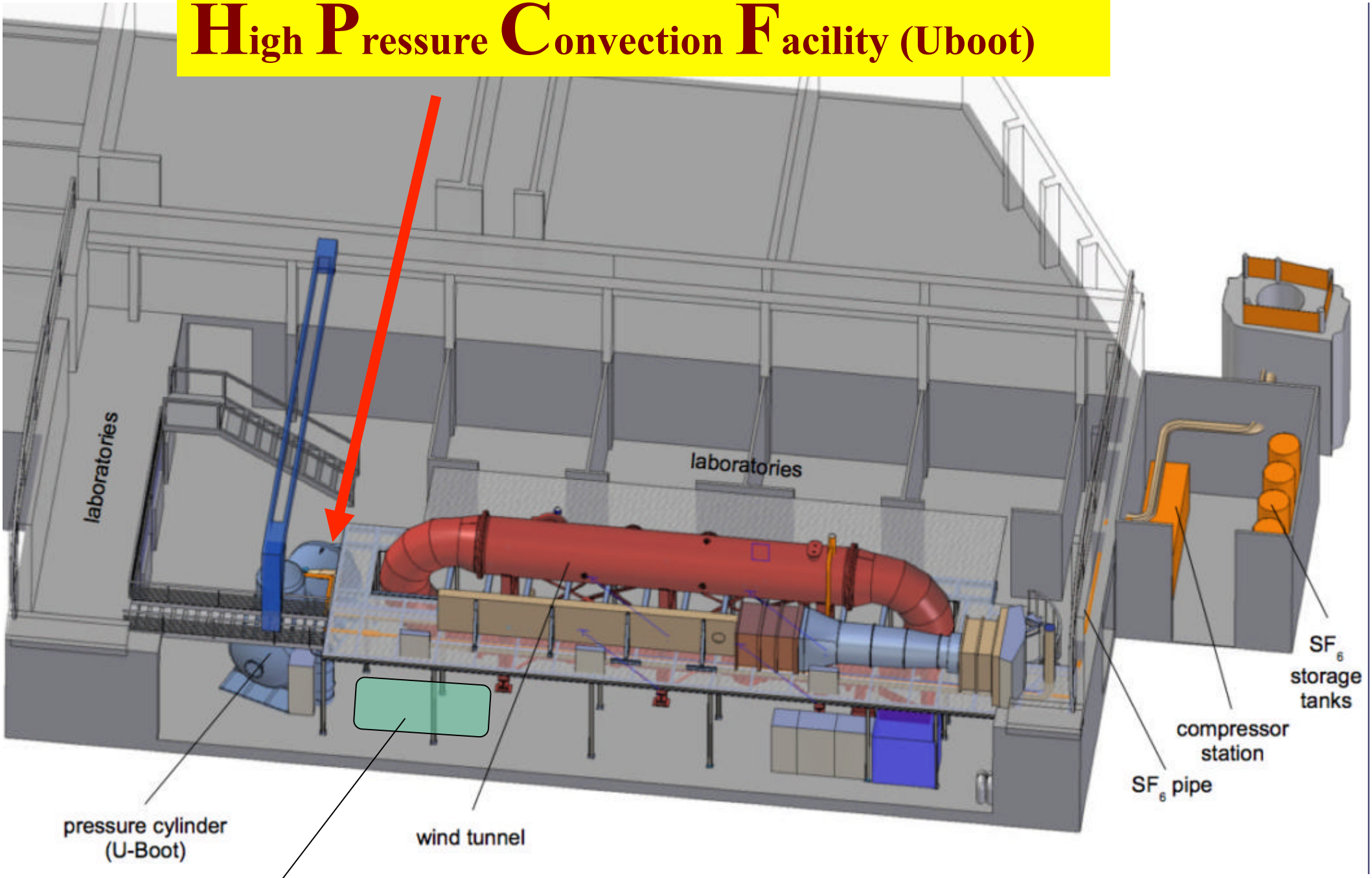
Lagrangian Exploration Module



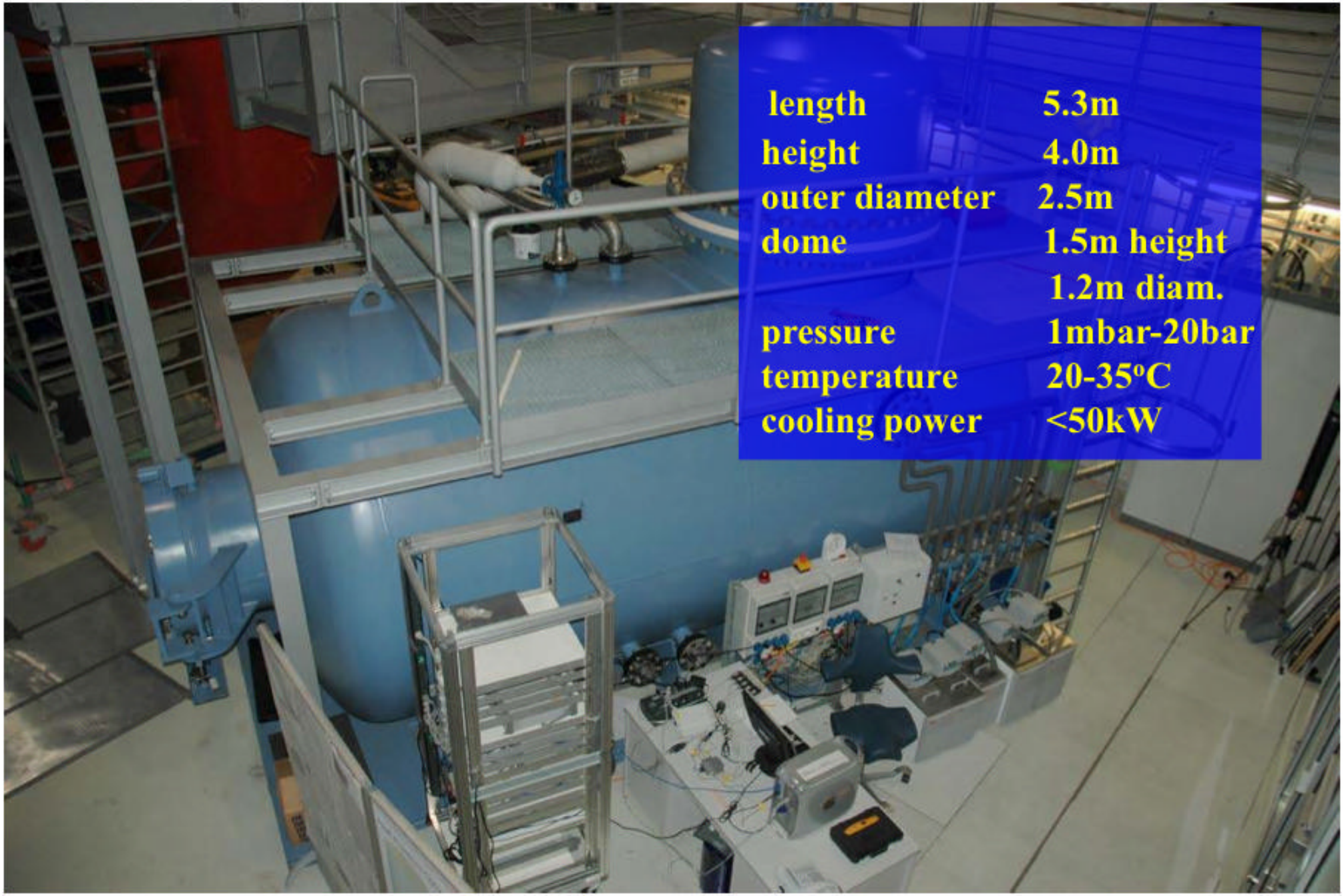




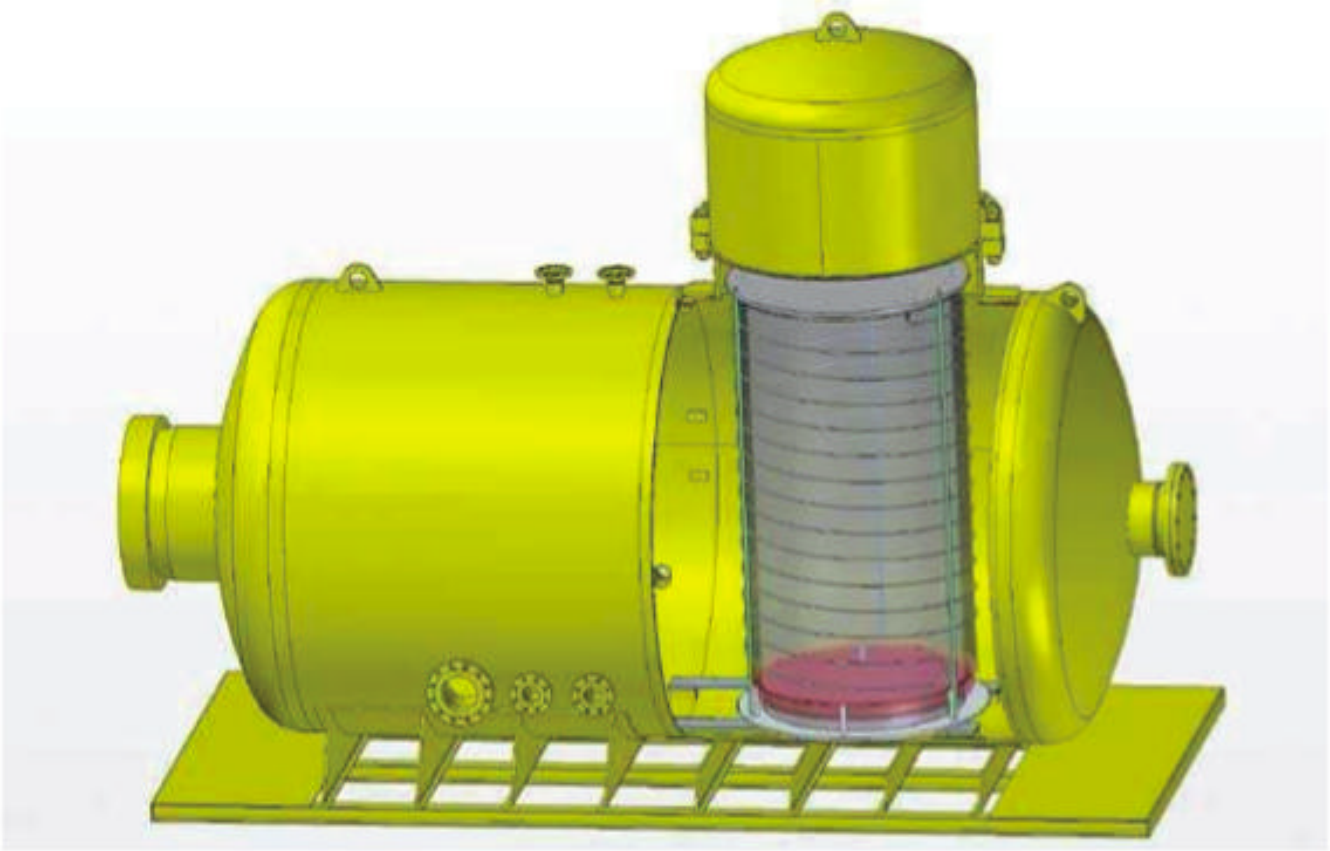
High Pressure Convection Facility (Uboot)

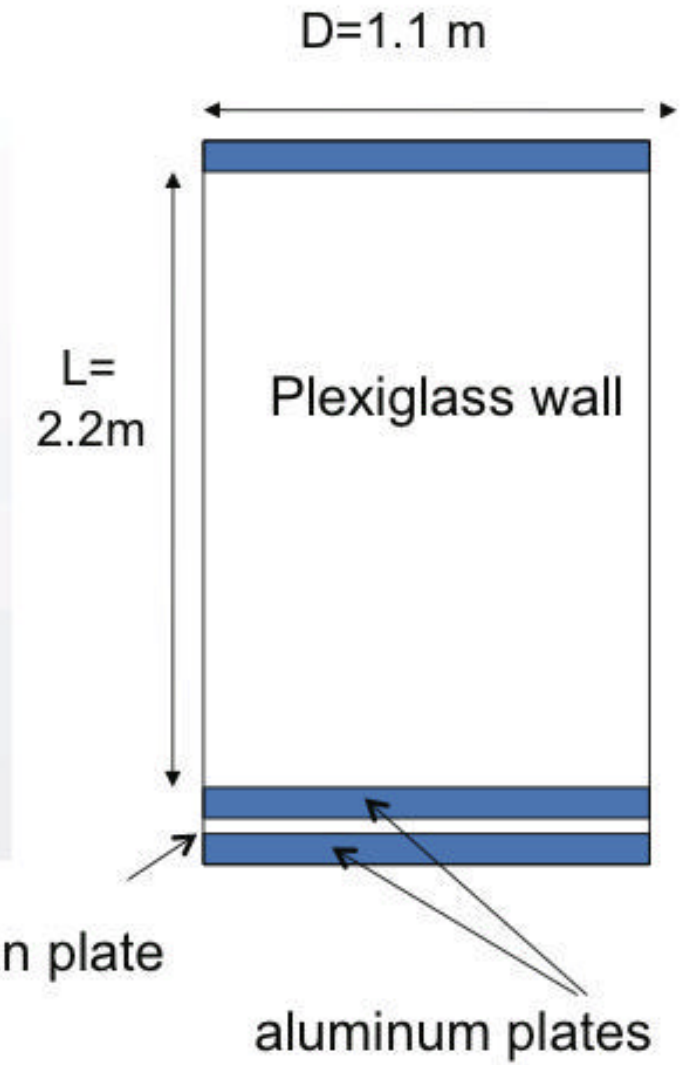


The Uboot

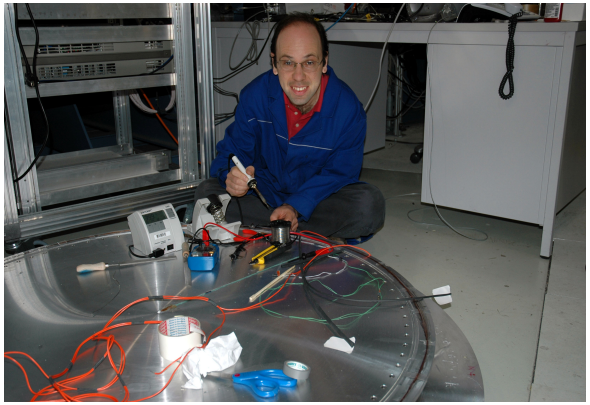

length 5.3m
height 4.0m
outer diameter 2.5m
dome 1.5m height
1.2m diam.
pressure 1mbar-20bar
temperature 20-35°C
cooling power <50kW

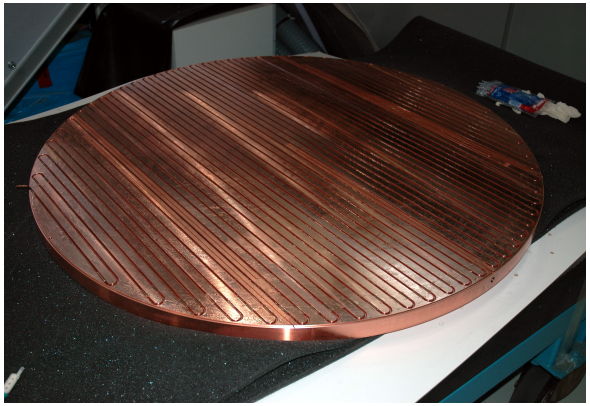
The convection cell in the Uboot

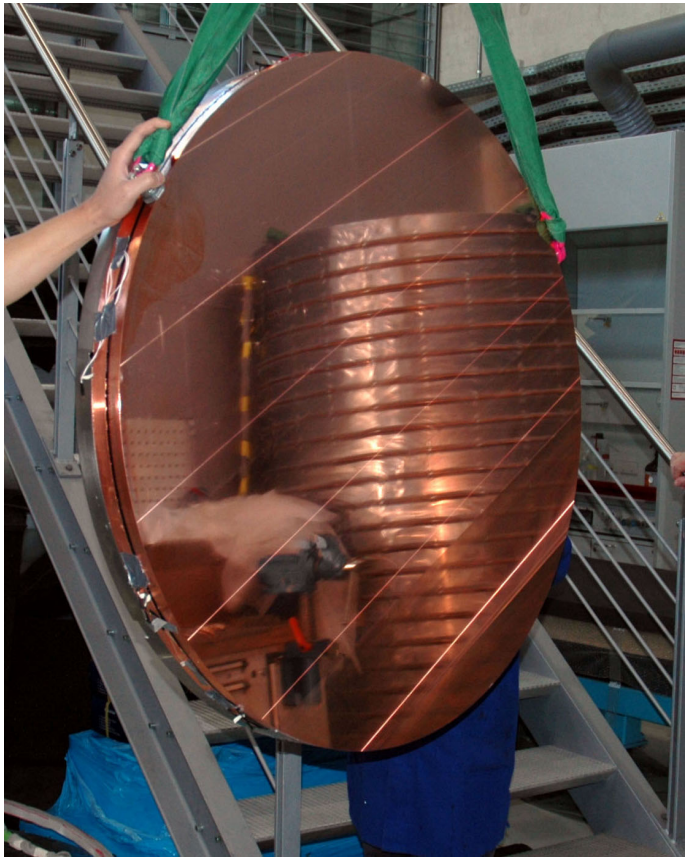


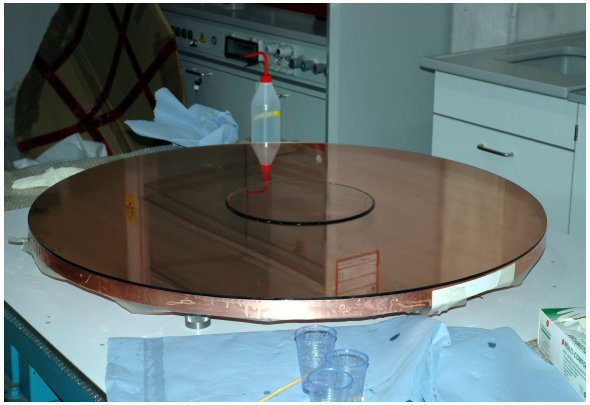


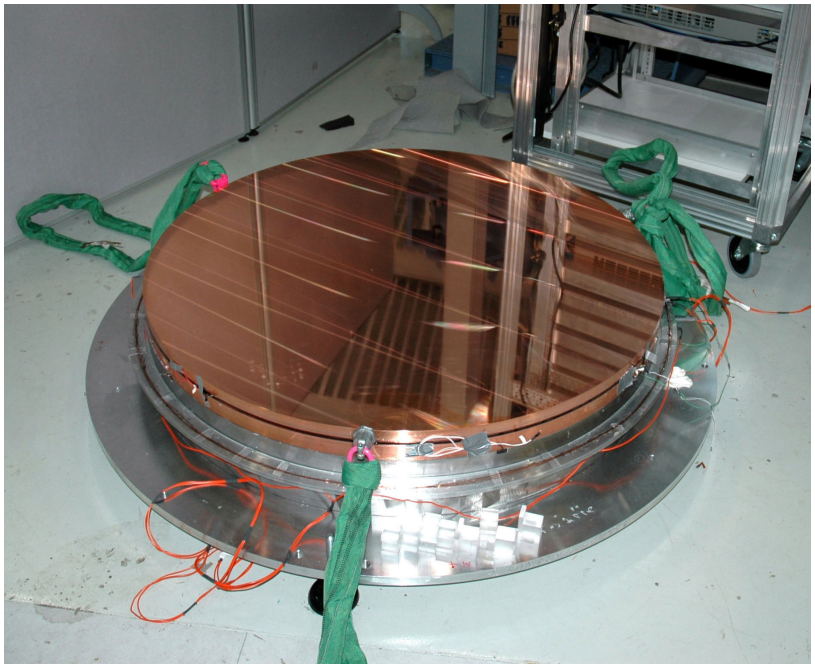
$Pr = 0.8$ and $10^{11} \leq Ra \leq 10^{15}$

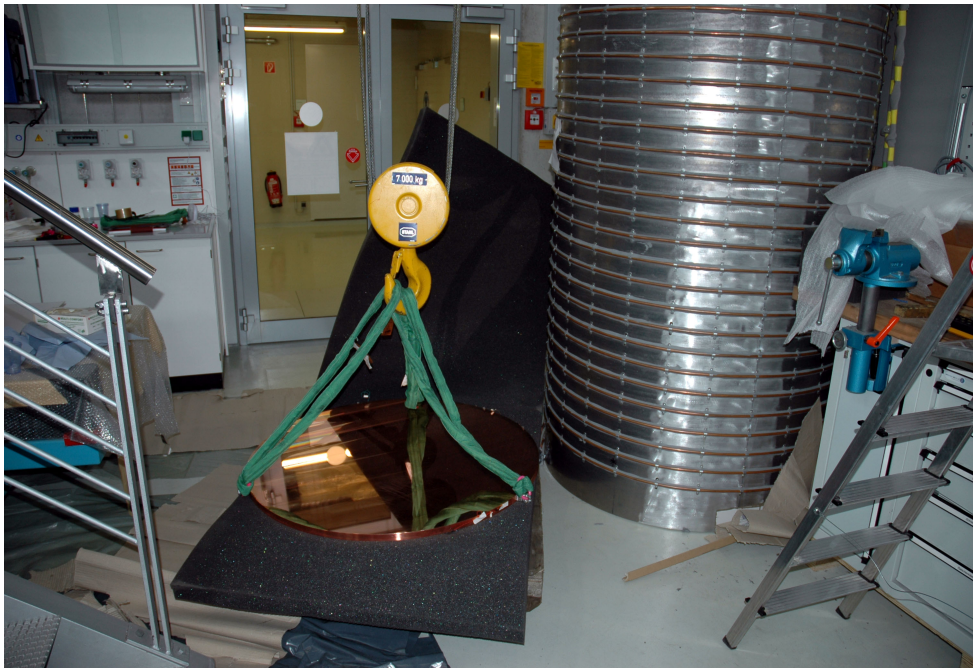


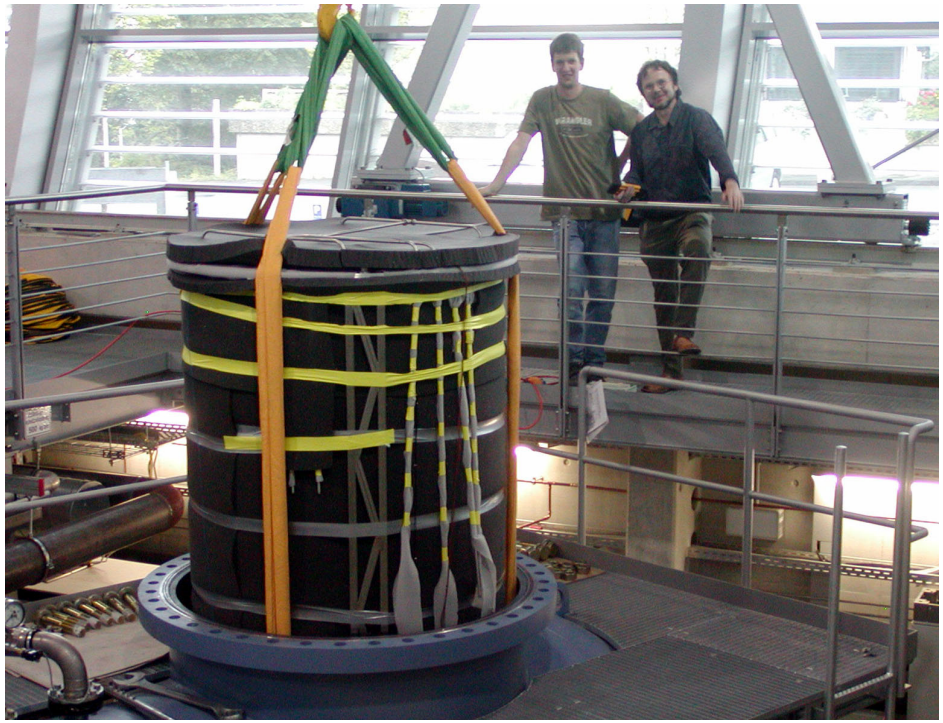


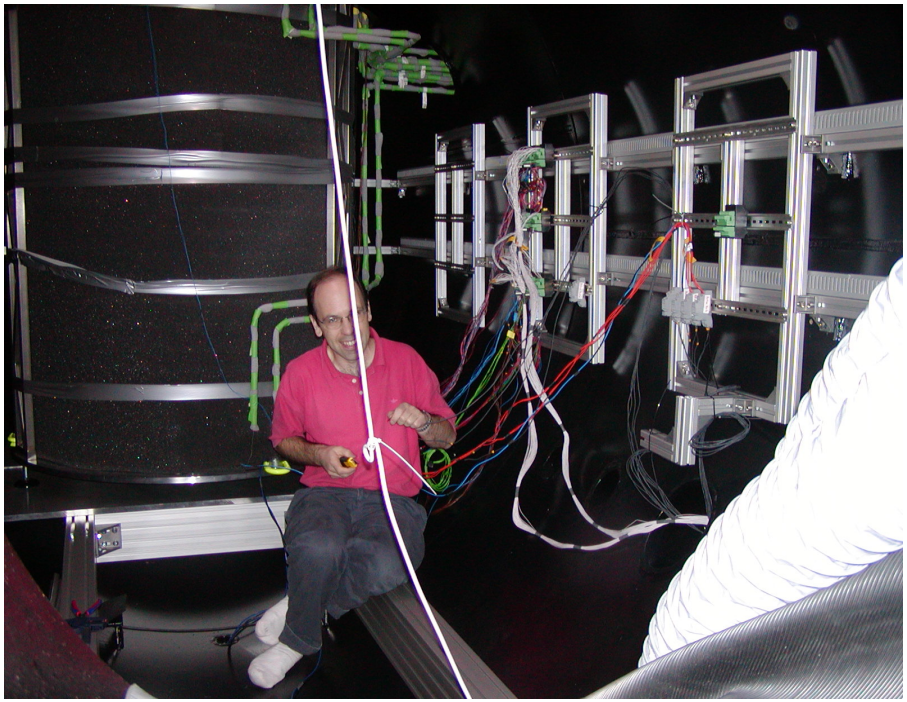




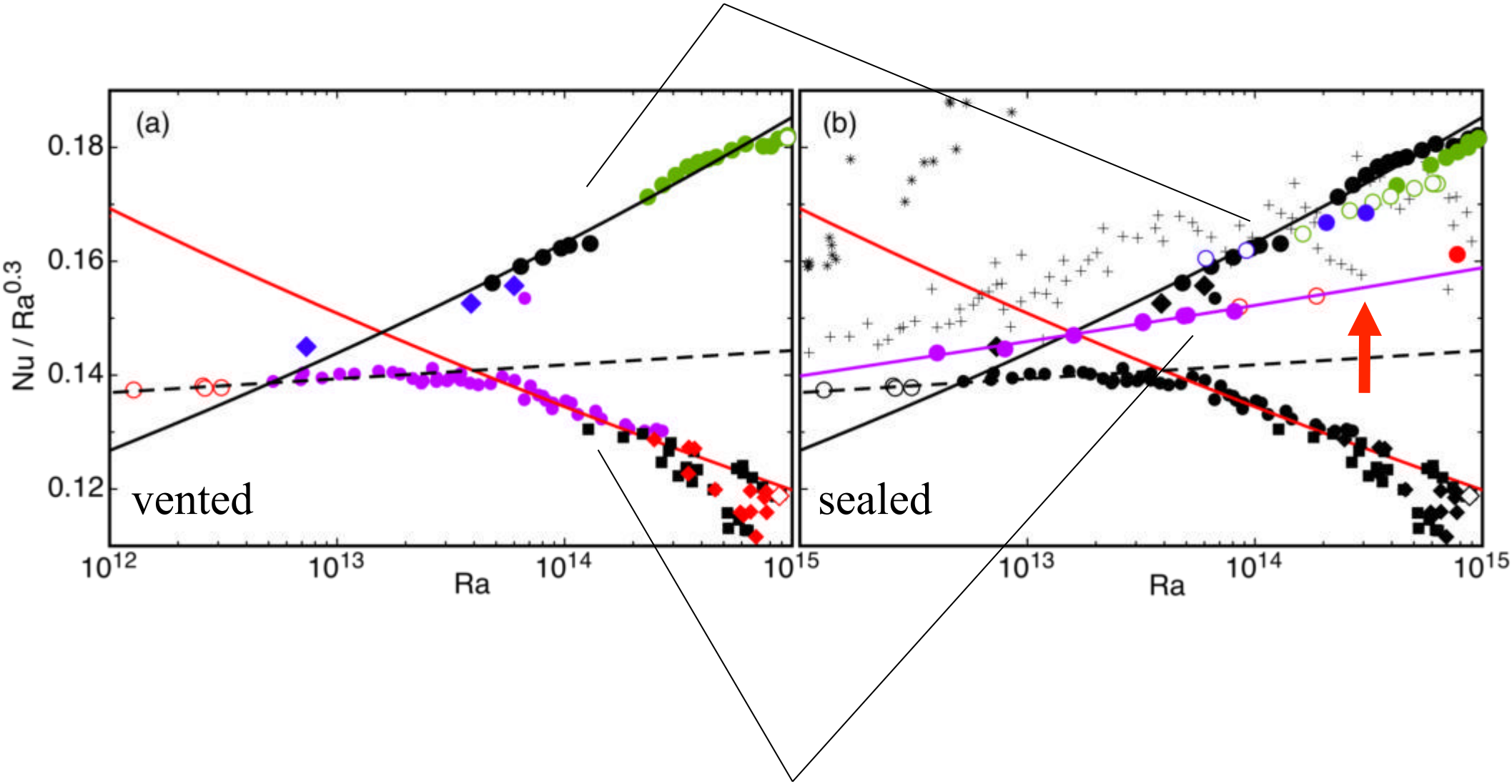








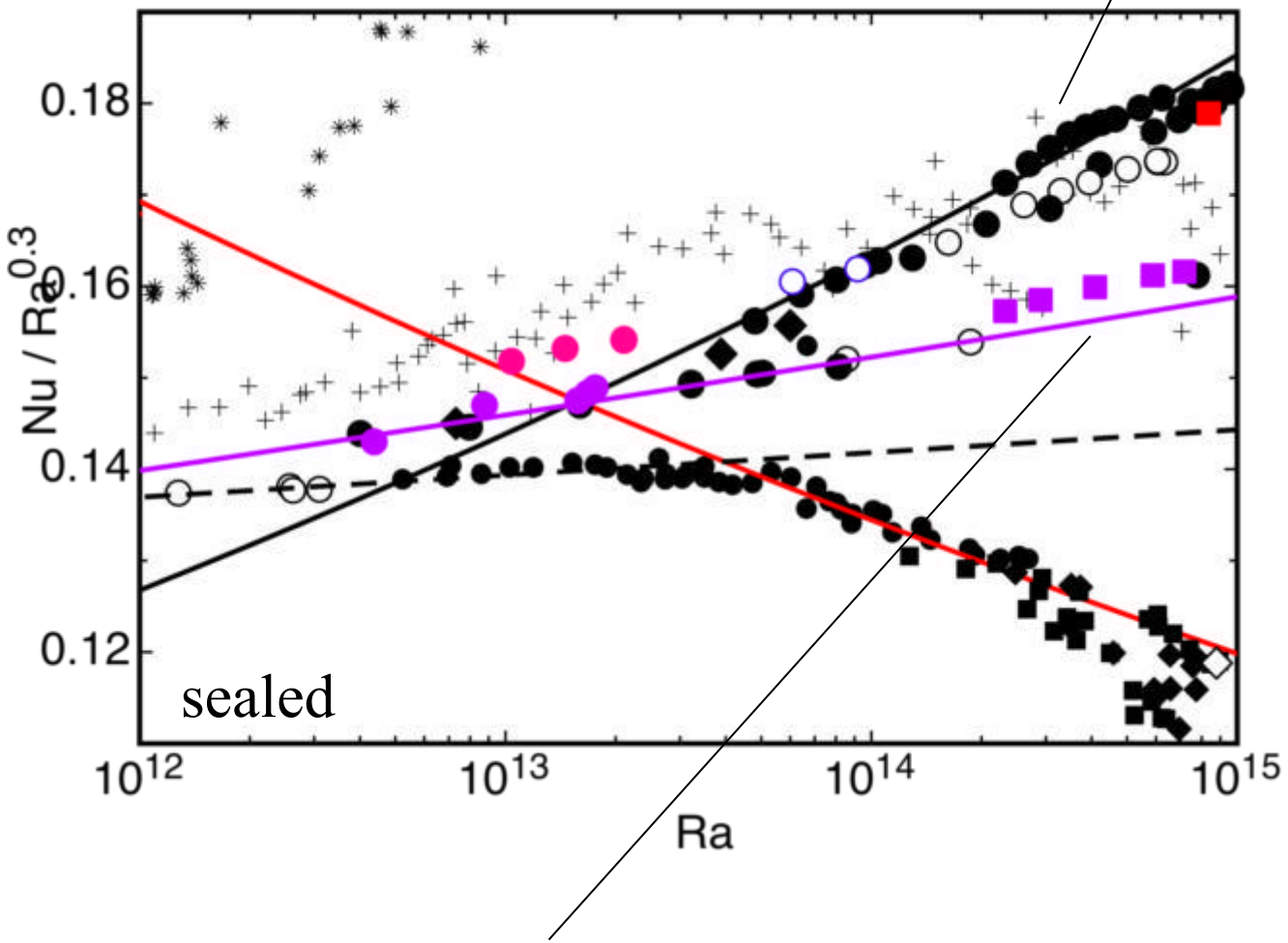
mean temp colder than Uboot



mean temp warmer than Uboot

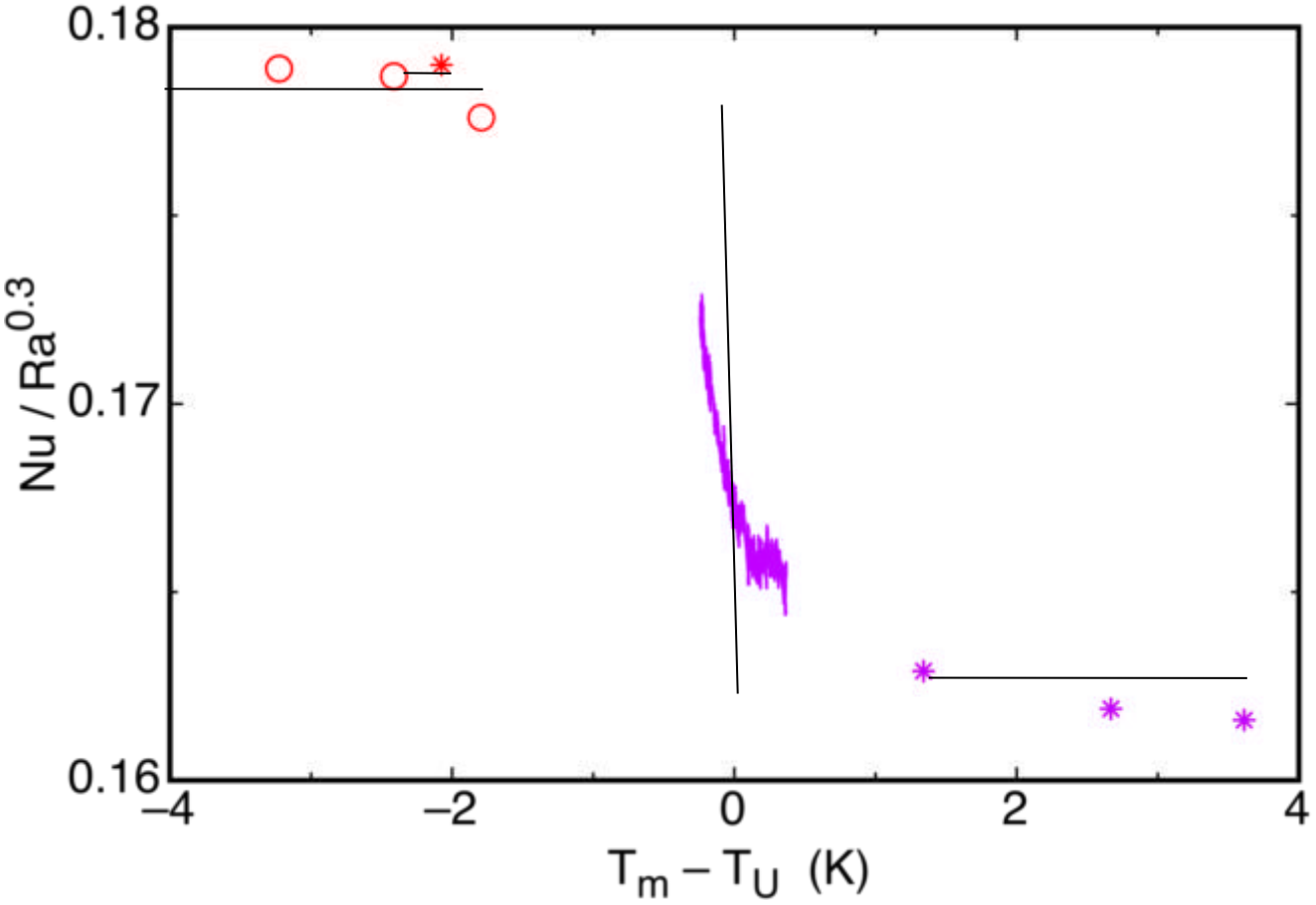
Inclined by 0.8 degree

mean temp colder than Uboot

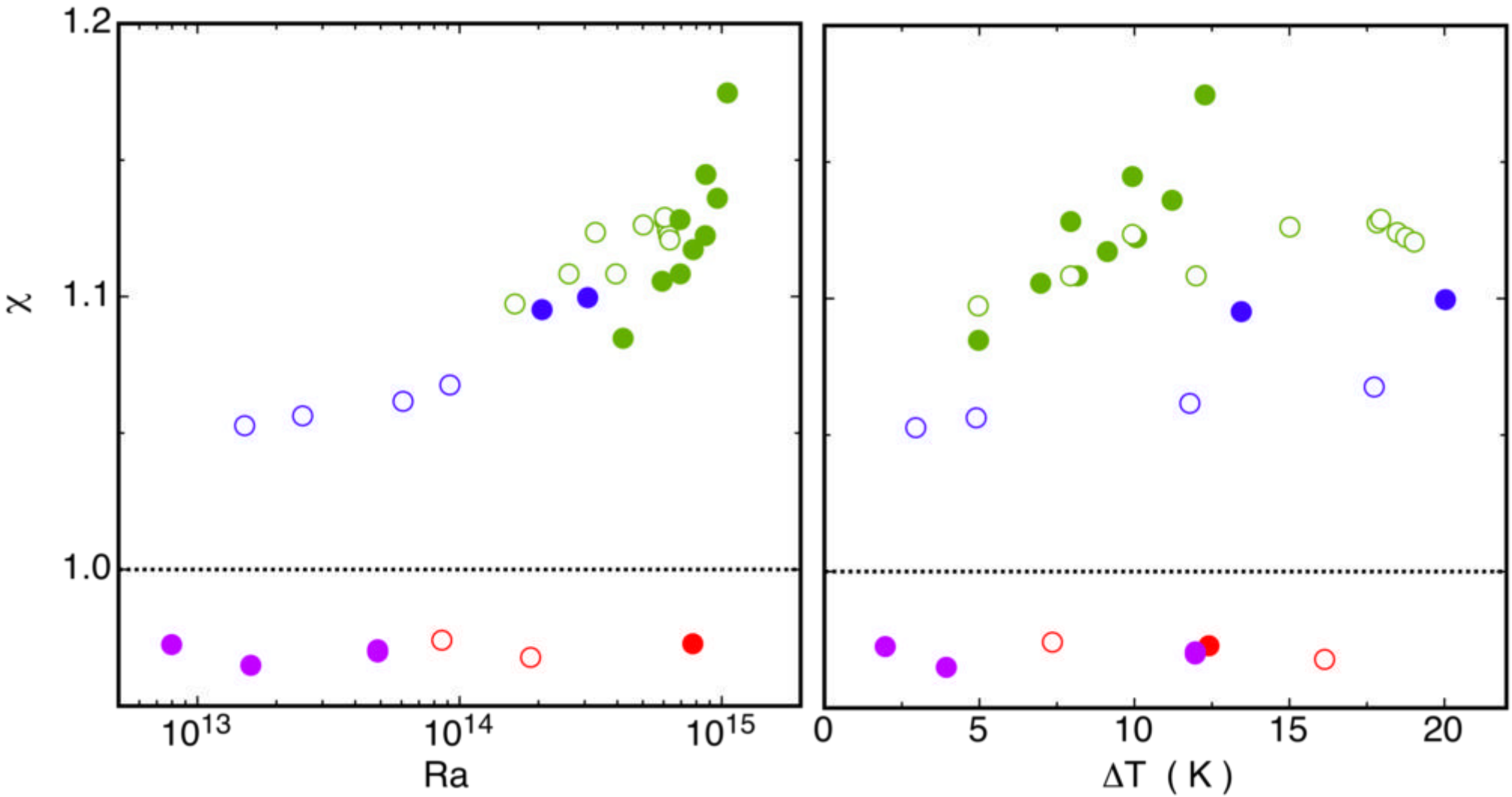


mean temp warmer than Uboot

two states only

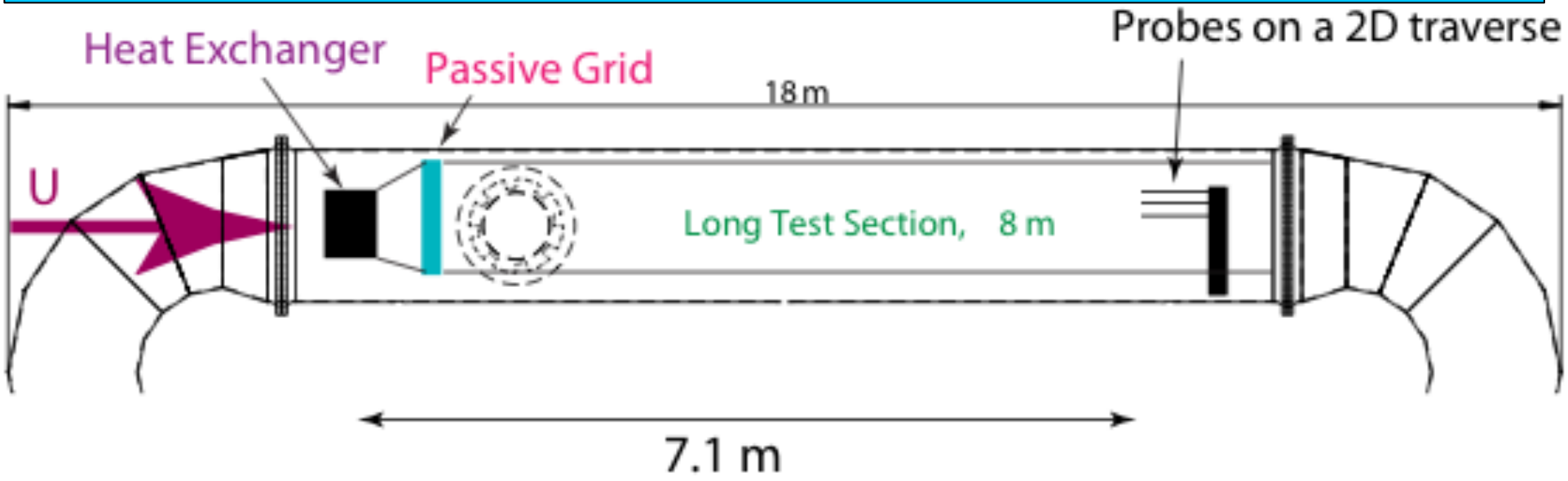


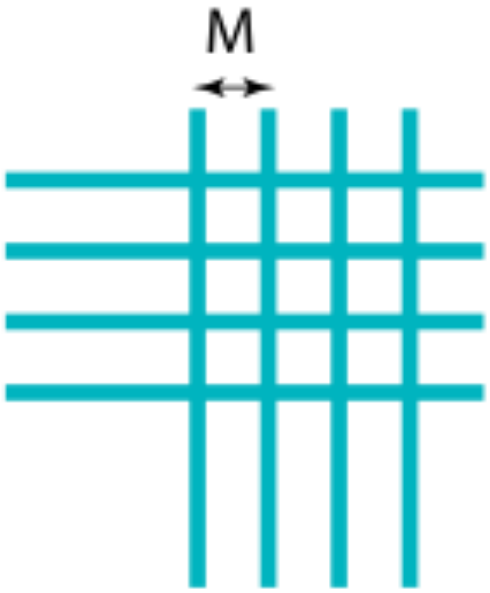
$$\chi = (T_{bot} - T_c)/(T_c - T_{top})$$



shift in upper branch depends on Ra not temp. difference

Passive Grid Turbulence in the VDTT





Passive Grid:

biplanar mesh of square bars with 35% solidity

mesh spacing, M = 107 mm

probes are x/M = 67 meshes downstream

Conditions under which data were taken

Working fluid	Pressure [Bar]	ρ [kg/m^3]	ν [10^{-6} m^2/s]	U [m/s]	u' [m/s]	ϵ [m^2/s^3]	R_λ	η [μm]	τ_η [ms]
Air	1	1.29	14.0	5.1	0.12	0.0080	148	806	43
SF_6	1	5.96	2.56	5.0	0.10	0.0089	294	215	18
SF_6	2	12.1	1.27	5.2	0.12	0.014	441	111	9.7
SF_6	4	24.7	0.620	5.1	0.11	0.0098	624	70	8.0
SF_6	12	82.9	0.190	5.2	0.13	0.013	1285	27	3.9
SF_6	15	108	0.149	5.2	0.13	0.0099	1706	24	3.9

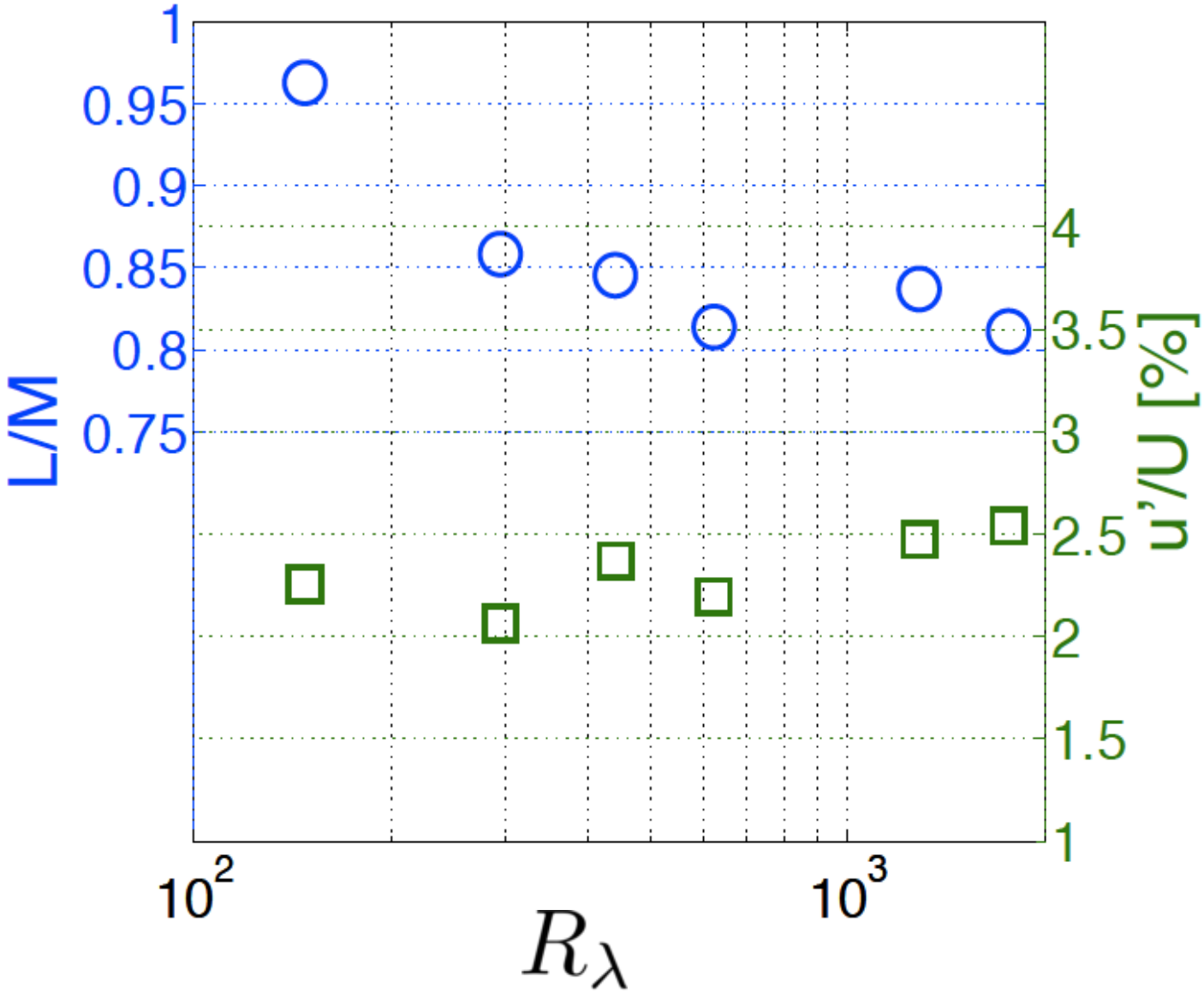
Table 1. A list the parameters for the passive grid experiments. In the calculation of R_λ, we determined the dissipation rates, ϵ, through Kolmogorov's $5/4^{ths}$ law and the Taylor scale through the isotropic relation $\lambda_g = (15\nu u^2/\epsilon)^{1/2}$.

$$D_{LLL}(r) = -\frac{4}{5}\epsilon r$$

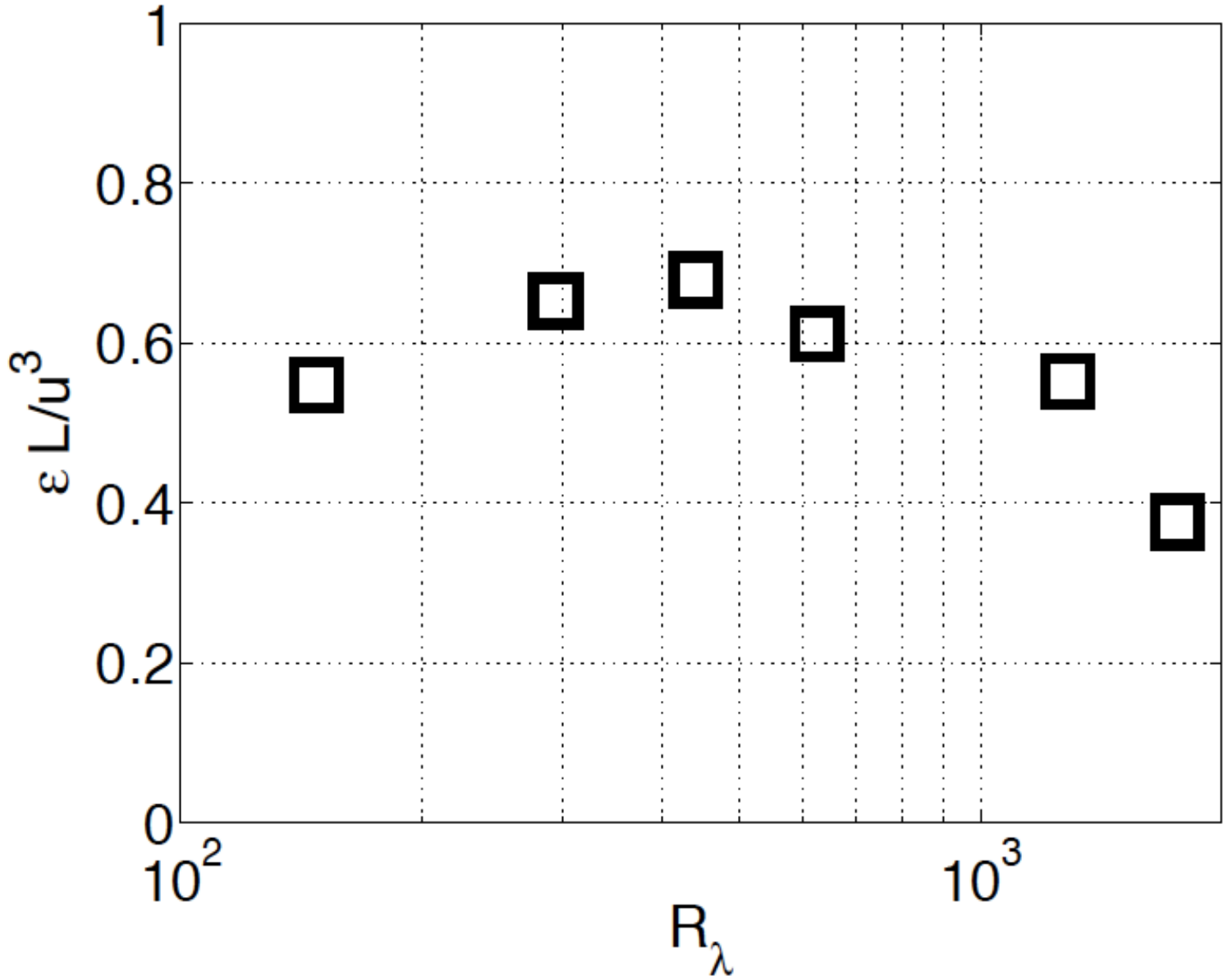
$$\lambda_g = \left(\frac{15\nu u^2}{\epsilon}\right)^{1/2}$$

$$R_\lambda = \frac{u\lambda}{\nu}$$

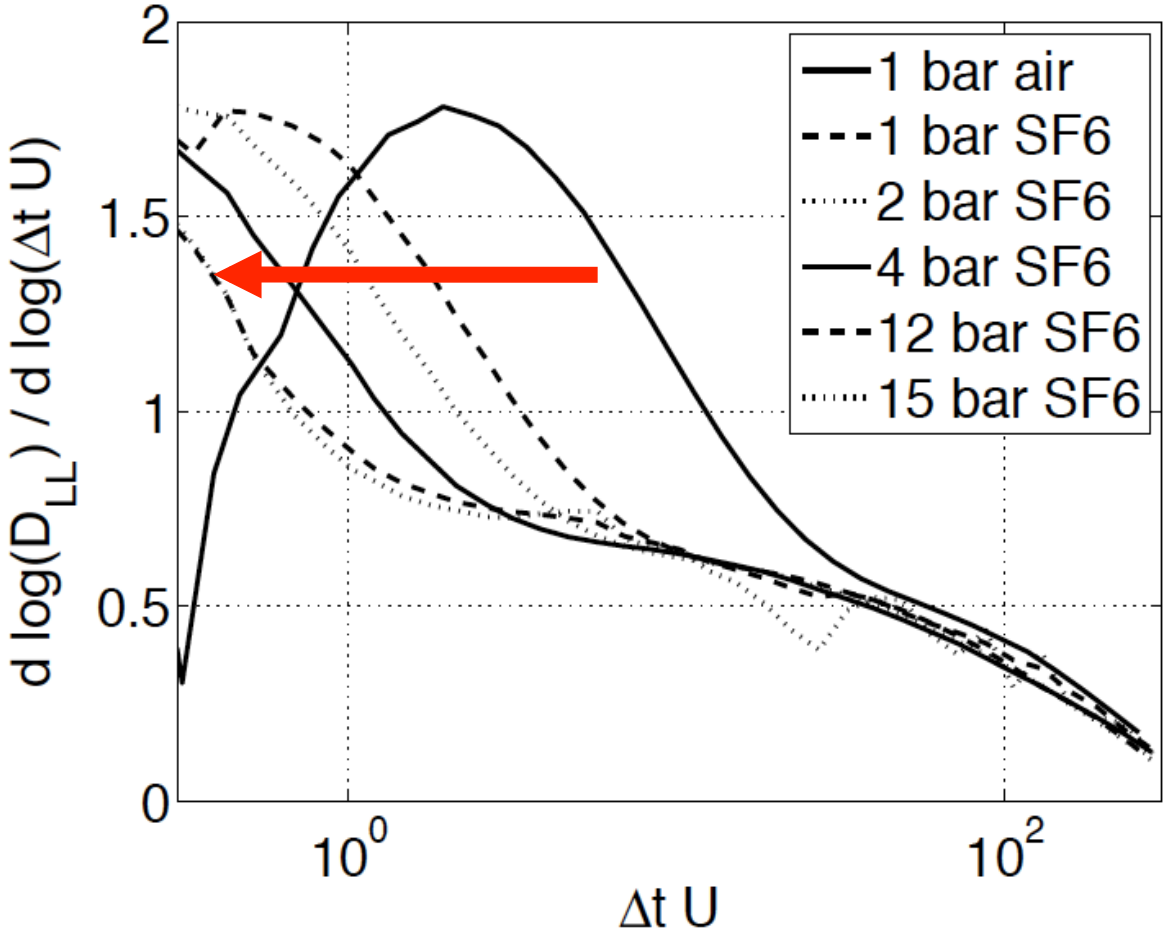
The large scales



Dissipation

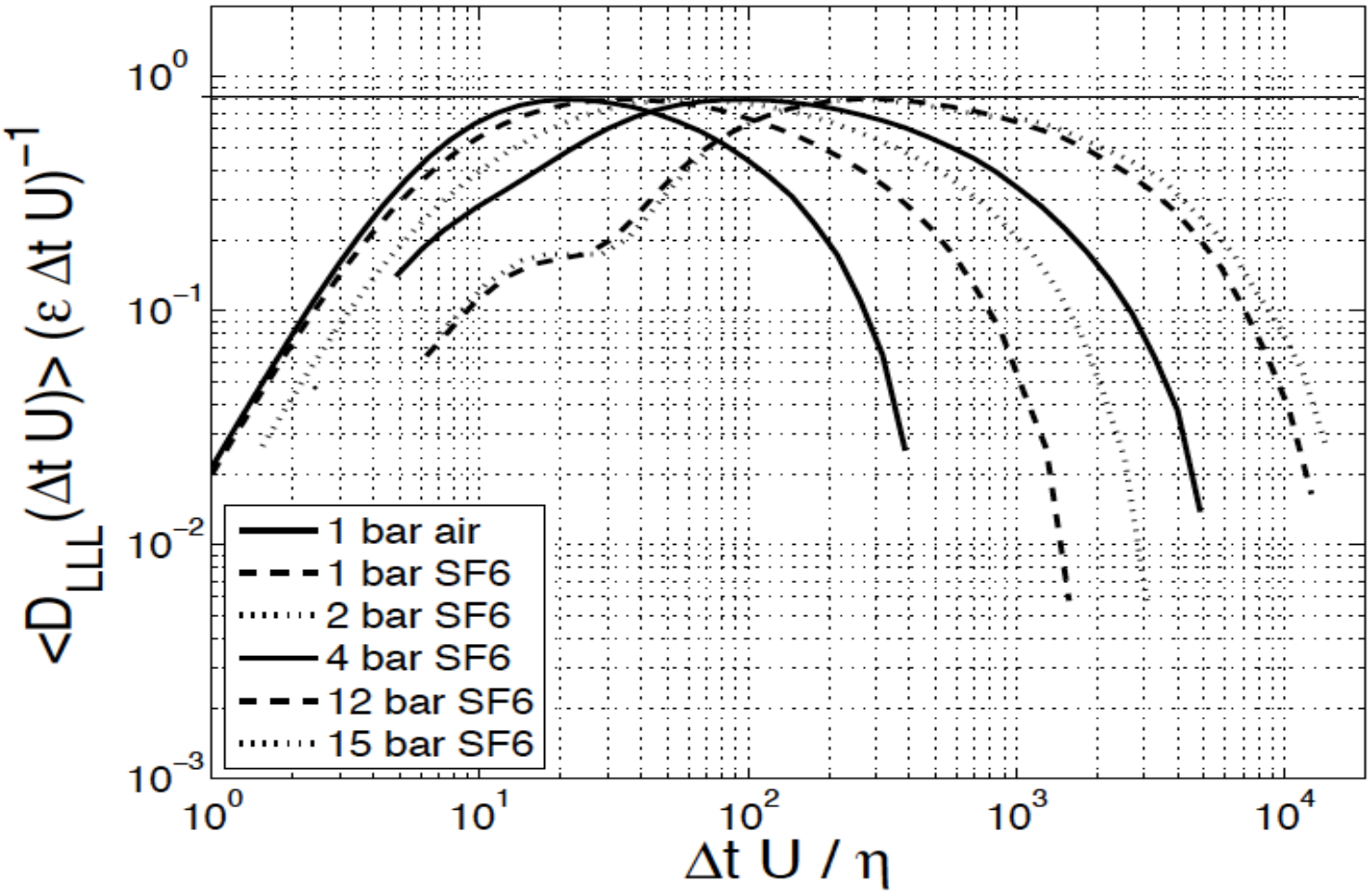


Local slope of second order longitudinal velocity structure functions

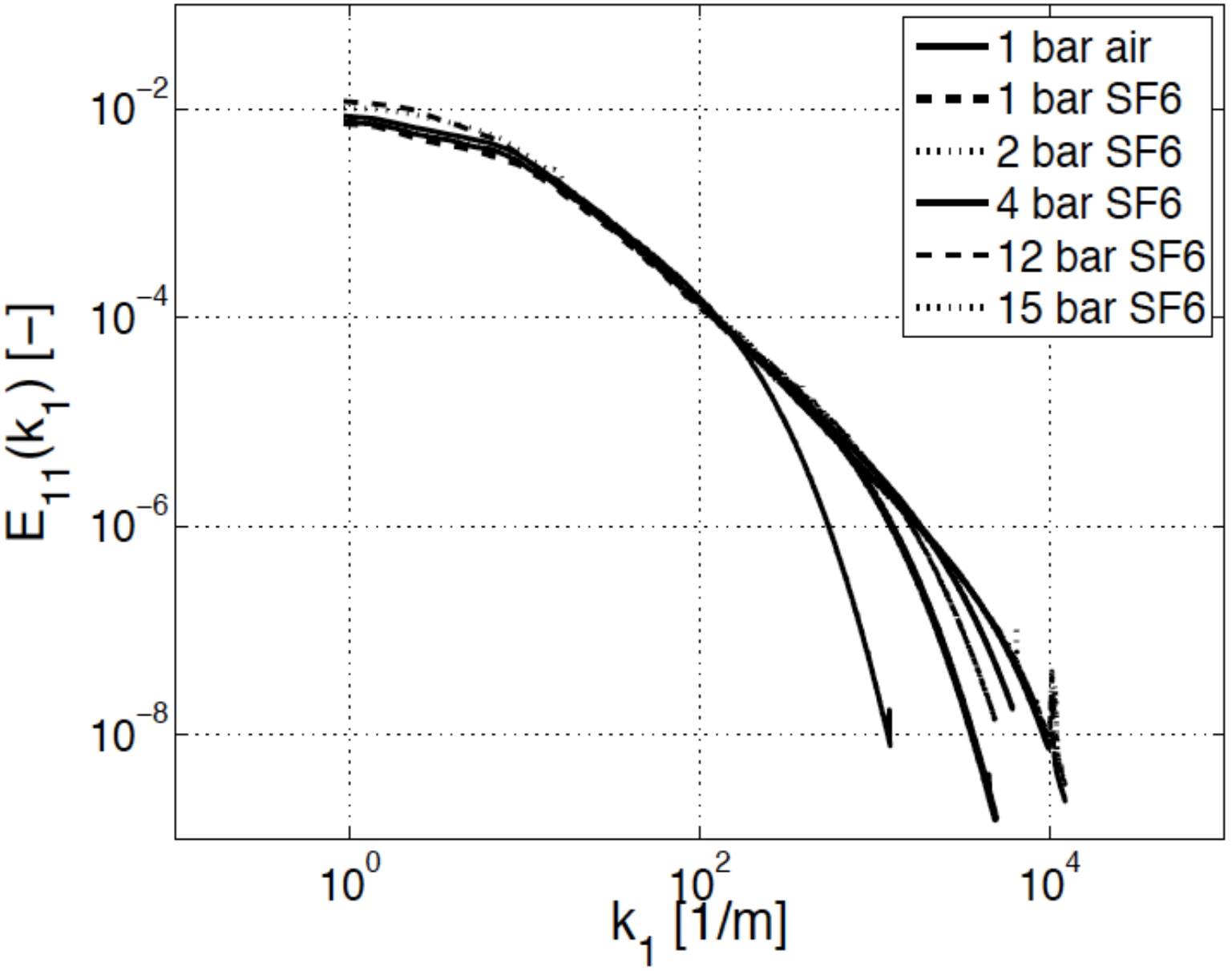


- small scales decrease

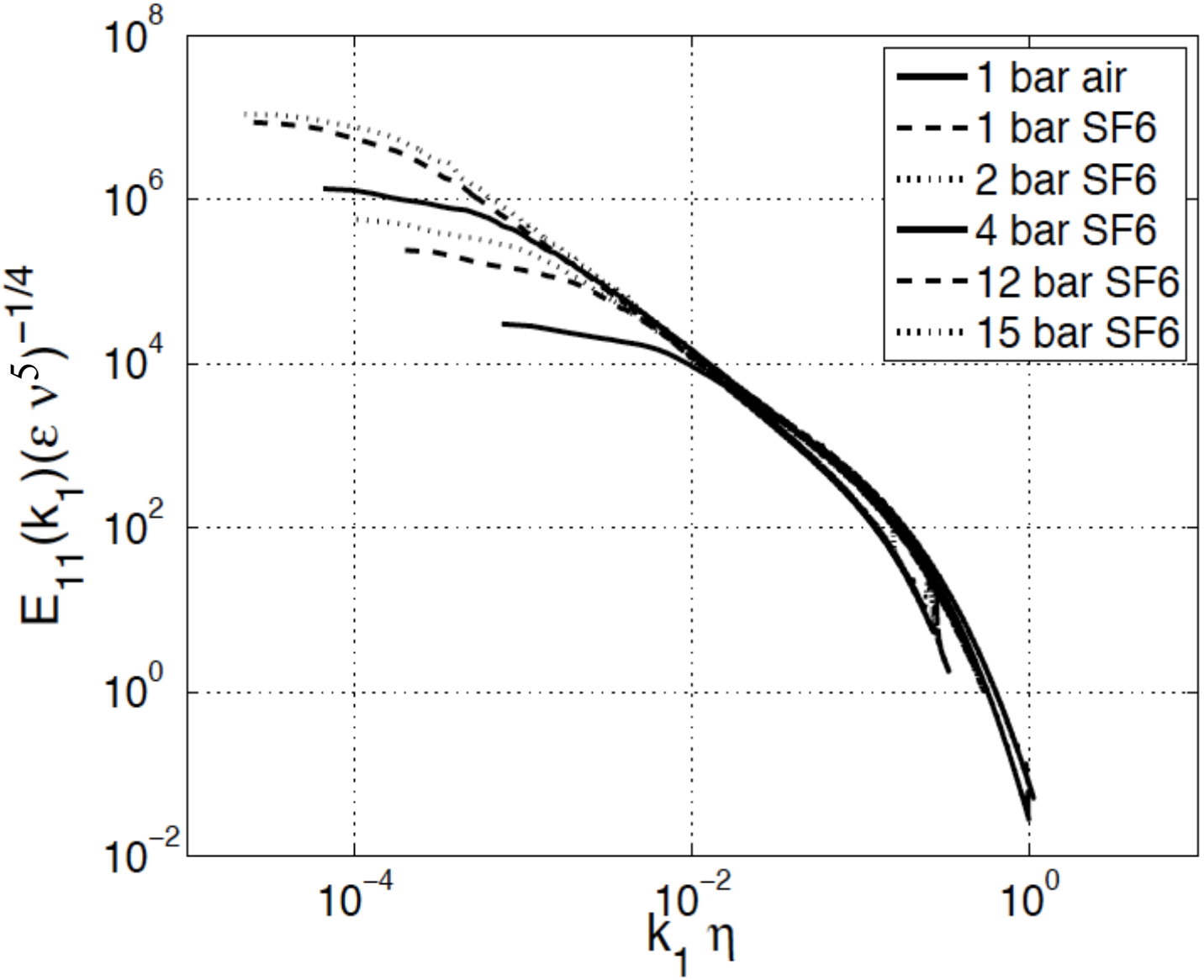
3rd order velocity structure functions



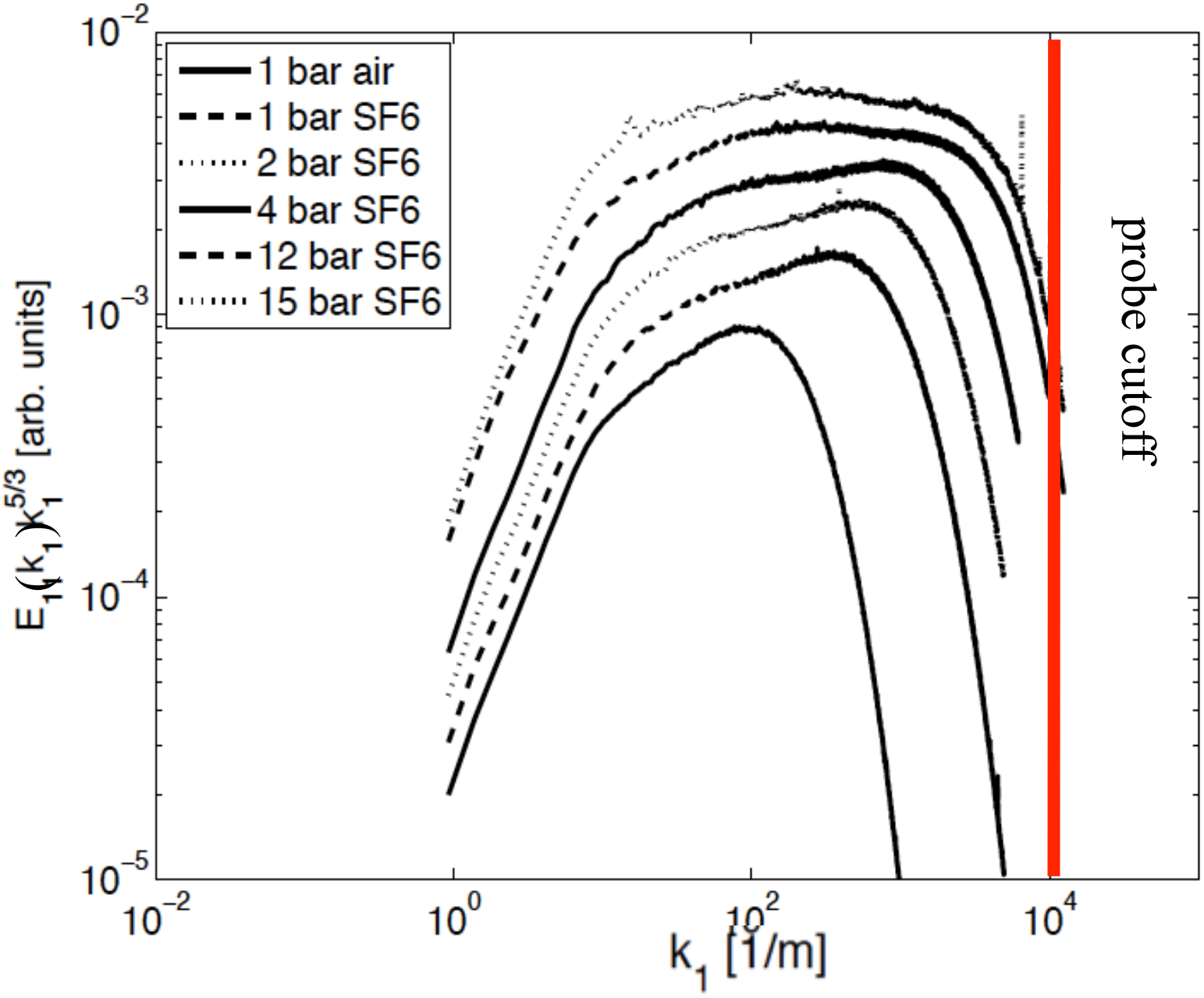
Energy Spectra



Energy Spectra



bottle neck grows and shrinks with Re



Predicted properties for the active grid

Working fluid	Pressure [Bar]	ρ [kg/m^3]	ν [$10^{-}6$ m^2/s]	U [m/s]	u' [m/s]	ϵ [m^2/s^3]	R_λ	η [μm]	τ_η [ms]
Air	1	1.29	14.0	5.0	1.0	1.33	850	210	3.2
SF_6	1	5.86	2.64	5.0	1.0	1.33	2000	61	1.4
SF_6	15	107	0.15	5.0	1.0	1.33	8000	7.5	0.35

Table 1. Parameters predicted for the active grid.

We have given a summary of the Goettingen Turbulence facility – more at http://www.ds.mpg.de

We thank the Max Planck Society and the Cost Action 806 by the European Community for support.